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FINAL REPORT
Period
1 July, 1973 to 30 June, 1976

Use Of Remote Sensing Techniques For Geological Hazard Surveys In Vegetated Urban Regions

NASA Contract NAS8-29937
Project 1-3-80-00085 (1F)

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ADDRESS: TUSCALOOSA, ALA.

September 16, 1976

Mr. Julian Gleaves, AP 13-C
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Al 35812

Dear Mr. Gleaves:

Enclosed is the final report (1973 - 1975) entitled "Use of Remote Sensing Techniques for Geological Hazard Surveys in Vegetated Urban Regions," NASA Contract Number NAS8-29937.

This report should be distributed as follows:

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Yours truly,

S. H. Stow

Stephen H. Stow
Associate Professor of Geology

lsw

cc: Mr. Thomas Bryant ONRR

Enclosures

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Use of Multispectral Imagery for Lithologic Mapping in a Heavily Vegetated Area

INTRODUCTION AND PURPOSE

Geologic and lithologic mapping, often considered synonomous with field geology, is a means of presenting large amounts of geologic data to other persons (Compton, 1962). Prior to the advent of aerial photography, mapping was exclusively conducted by field parties. "Advances in aeronautics during World War I were largely responsible for stimulating commercial use of aerial photography during the 1920's" (Drahovzal & others, 1976). Increased usage of aerial photographs eliminated "man hours" in the field and air photo interpretation became a fundamental part of topographic and base map preparation, as well as an aid in geologic mapping.

Early interpreters used black and white aerial photographs which recorded reflected light (electromagnetic radiation) of the entire visible spectrum. Techniques and illustrations of black and white aerial photograph interpretation are presented by Smith (1943), Ray (1960), and Avery (1968). In recent years, air photo interpretation has become more applicable to geologic problems because of advances in sensor devices and the advent of space photographs. Sensor devices have been developed which collect light of specific wavelengths instead of the entire range of the visible spectrum (.38-.79 microns). Photographs recording reflected light of specific wavelengths, multispectral imagery

(Colwell, 1968), give a more detailed view of the earth's surface. Reflected and emitted electromagnetic radiation with wavelengths longer than visible light are recorded as infrared and thermal infrared images, respectively. Bastuscheck (1970) explains the theory and principles of thermal infrared imagery while Lyon (1970) and Matsuno (1970) show potential application of infrared and thermal infrared imagery to geologic problems. According to Short and Lowman (1973) orbital or space photographs were first utilized for geologic studies in 1963 by P.M. Merifield who demonstrated the importance of the synoptic view provided by the high altitude photos. Throughout this report the term "space photograph" refers to photos taken from satellites (Gemini, Apollo, Skylab, ERTS, etc.) orbiting the earth (approximately 100-500 miles high). On the other hand, usage of the term aerial photograph has been restricted to photos taken from non-orbiting aircraft within the earth's atmosphere (generally less than 70,000 feet). Geologists should bear in mind, however, that air photo interpretation is a tool aiding in the solution of field oriented geologic problems and should be used in conjunction with field work. Photo interpretation is merely a means to reach an end and is not an end within itself.

The primary objective of this study is to examine the feasibility of using aerial photography for lithologic differentiation in a heavily vegetated region. Numerous articles concerning geologic and lithologic mapping (El-Shazly and others, 1974; McKee and others, 1973; McKee and Breed, 1973; Melhorn & Sinnock, 1973; Brennan and Lintz, 1971; Ramanova, 1971; Wolfe, 1971; Matsuno

and others, 1970; and Sabins,1967) and soils mapping (Dillman & Vincent, 1974; Westin, 1973; and Planet, 1970) in sparsely vegetated regions, have been published. Colwell (1968), referring to exposed material, emphasized the importance of determining the specific wavelength of light where target response "stands out" against background radiation or "noise". Salisbury and Hunt (1974), Watson (1972), Lyon and Patterson (1969), and Lyon and Patterson (1966) all report techniques for differentiating exposed rock units. Few articles, however, have been published concerning geologic, lithologic, and soils mapping in heavily vegetated regions. These papers are restricted to techniques of broad regional geologic and lithologic mapping (Gold et al, 1973) Grootenbore, 1973; Hughes, 1973; and Rowan and others, 1973) and to regional soils mapping (Liang, 1964; and Caiger, 1970. Caiger (1970), differentiating soil units by using aerial photos, but being unable to identify the units until collecting field data, emphasized the need for field work in conjunction with photo interpretation. The majority of existing studies concerning heavily vegetated regions are general and few attempts have been made to evaluate objective capabilities of such studies. "Local" lithologic differentiation, using space and aerial photographs, has not been attempted in heavily vegetated regions.

Direct spectral responses of different rock types can not be used satisfactorily for differentiaing lithologies in a humid region. Natural vegetative covering, topography, land use patterns, moisture bearing properties of surficial material, and soil zones all tend to mask spectral reflectance and emittance of underlying lithologic units. Since data collected by remote sensors are primarily controlled by vegetation and totpography, these

factors have been examined in relation to underlying rock types for this study. Colwell (1968) expressed the need to integrate all the properties of a photograph in order to differentiate lithologies in a humid region.

Natural vegetation is restricted to localized plant zones (Harper, 1913). Localized plant zones result in categorizing plants according to their morphological and physiological similarities. Delineating and mapping of localized vegetal zones could be accomplished by the use of remote sensing since a difference in morphology and physiology results in different natural reflectances or signatures (Knipling, 1970). As a portion of this study, an investigation has been made to show that these local plant zones are affected, but not controlled by, altitude, topography, weathering, and gullying, but are controlled by lithology. Therefore, maps outlining local plant zones have been used as a basis for lithologic map construction.

METHOD OF STUDY

Imagery from The University of Alabama ERTS Project (NAS8-21976) flown on May 8, 1973, at an altitude of 12,500 feet (3850 meters) was studied. This multispectral imagery represents light recorded at four specific wavelengths within the 0.4 to 0.9 micron range. Four photographic prints were made, one for each band, corresponding to the specific wavelengths of light recorded. Conventional photographs, however, represent recorded light of the entire visible spectrum and only one composite photographic print is made of each scene. The four multi-spectral bands available are as follows: 1) band 1 (blue) 0.40-0.48 microns; 2) band 2 (green)

0.48 -0.59 microns; 3) band 3 (red) 0.59-0.70 microns; 4) band 4 (infrared) 0.73-0.90 microns. Bands 1, 2, and 3 fall within the range of visible light, whereas band 4 (infrared) has a wavelength longer than those of the visible spectrum.

Non-automated visual interpretation involves spontaneous recognition, ground truth acquisition, and logical inference (Meer Mohr and Krishnanunni, 1971). Short and Lowman (1973) state that automatic processing has not been as effective as subjective observations by the interpreter. Automated data processing is commonly used when analyzing large quantities of data. Some remote sensors record electromagnetic radiation in 18 bands. If diagnostic signatures could be recognized on these bands then automated processing would prove beneficial. Since this study was utilizing only four multi-spectral bands and since numerous variables were considered during analysis, interpretation was by subjective observation. Although some enchancement was used (color additive viewer), final interpretation was subjective. See Anuta and others (1971), Kristof and Zachary (1971), and Melhorn & Sinnock (1973) for discussion concerning automated analysis of multispectral imagery. Although this study involved non-automated visual interpretation, it remained objective by explaining causal relationships between tonal and textural qualities of the photo and terrain parameters (ground truth).

Type of photographs, conventional black and white, multispectral, and color infrared, which are most conductive to differentiating lithologies in humid regions have been determined.

Emphasis has been placed upon determining optimum time of flight and especially proper enchancement techniques of photographs.

Multispectral imagery was analyzed as positive transparencies, Kodalith and Panatomic-X positive prints, false relief positive prints, and also by color additive viewing techniques. After determining optimum enhancement, ground truth data were compared with the enhanced photos and photographic signatures were ultimately developed for different lithologies.

The Cottondale Quadrangle was the area for collecting ground truth data. Existing geologic and lithologic maps of the Cottondale Quadrangle (Stow and Hughes, 1976) were utilized as ground truth in conjunction with vegetative, moisture, and grain size analyses of select areas within the quadrangle. Additional field mapping was also conducted within the study area.

Properties of photographs, such as tone and texture, were intergrated and analyzed with the realization that they represent secondary and tertiary evidence regarding underlying lithologies. Woodring and West (1974) stress the need for understanding the relationship between earth materials (ground truth) and photograph tonal response. Spectral responses of different surficial materials were analyzed with regard to tonal qualities of the photo. Photograph tone and texture are principally controlled by drainage characteristics (erosion, gulleying, and drainage pattern), landforms (topographic

expression, slope angle, and microclimatic differences), and vegetative cover. Relationships between these above mentioned factors and specific lithologies were also determined, however, before inference was made comparing tonal and textural qualities of photographs to specific lithologies. The surface characteristics act as an intermediate stage between the end member of photograph tone and texture and the end member of lithologic differentiation.

Tonal and textural overlays were constructed with no regard to ground truth and were compared with lithologies of the area. Percent correlation between overlays and lithologies was determined by using a polar planimeter. Overlays were also constructed with regard to existing ground truth.

A microphotometer was used to determine percent light transmission of select locations within the study area. Percent light transmission was ultimately compared with quantitative grain size and moisture analyses. The vegetal analysis was also subjectively compared with percent light transmission. After these quantitative and subjective comparisons, signatures were developed for specific lithologies.

LOCATION OF STUDY AREA

Because of lithologic diversity and also because of the applicability of the technique developed in this report to a wide geographic area, the Cottondale Quadrangle, Tuscaloosa County, Alabama was chosen as the area for study. (figure 1)

Exposed geologic units, ranging in age from Pennsylvanian to Holocene, consist of non-indurated Coastal Plain sediments,

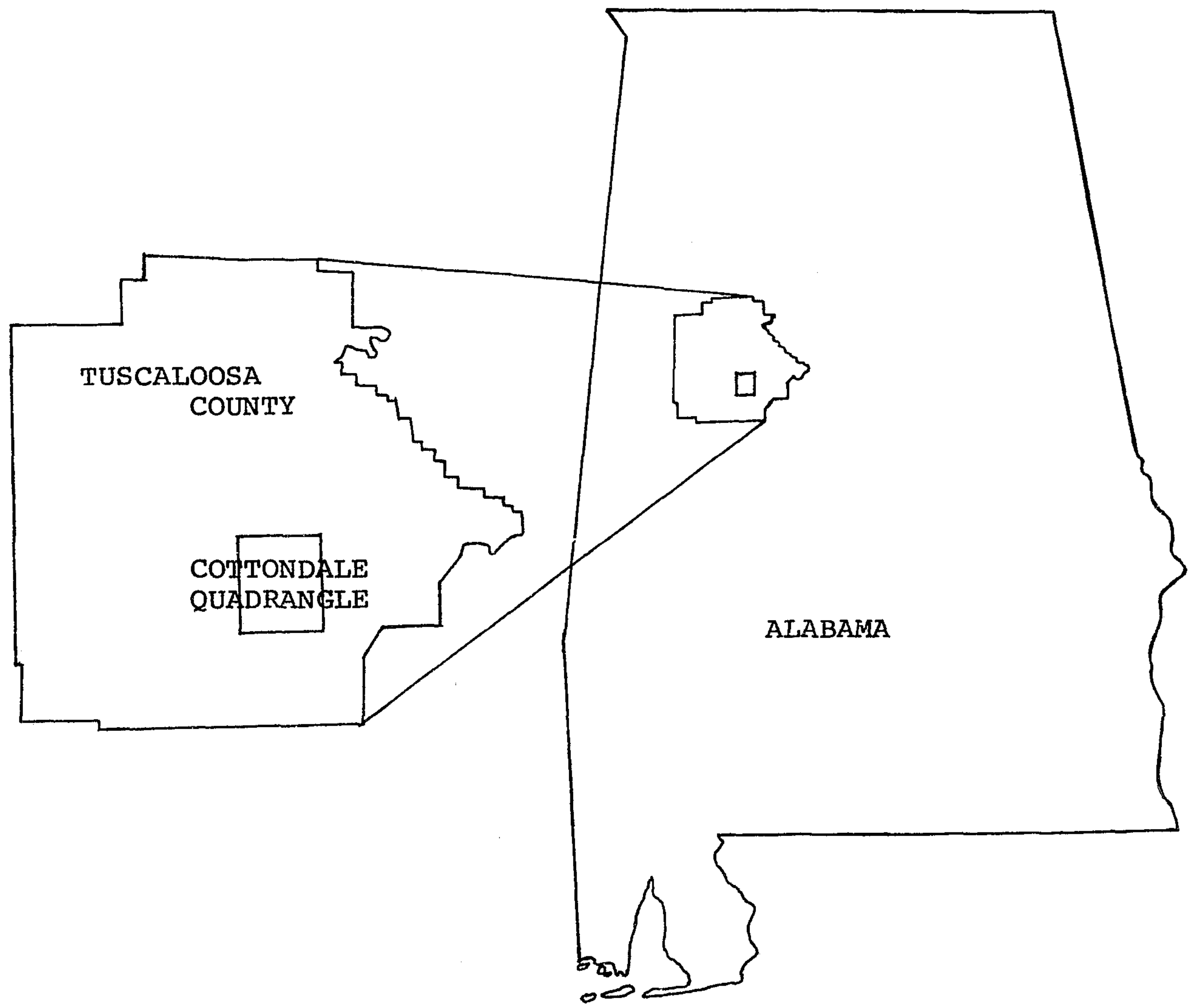

FIGURE 1
LOCATION OF STUDY AREA

weathered and indurated units of the Appalachian Plateau, and terrace deposits. Recent alluvium borders the major steams in the area.

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The authors wish to express thanks to Roger Shotts, Ridg Mullins, Ken Whetstone, and Charles Wielchowsky for aiding in field work and gathering of data. Thanks are also due to Dr. James H. Darrell, II, Georgia Southern College, for analyzing samples for microfossils and to Jacques Emplaincourt and Dan Sapp, Remote Sensing and Topography Division--Geological Survey of Alabama, for technical advise and use of equipment.

GROUND TRUTH

The Cottondale Quadrangle was the area of study for collecting ground truth data. Vegetative, moisture, and grain size analyses were conducted of selected areas within the quadrangle. Existing geologic and lithologic ground truth data were also used as a part of this study.

Stratigraphy

Pottsville Formation

The Pottsville formation consists of shale, siltstone, sandstone, conglomerate, and beds of coal. In the study area only the upper portion of the formation is exposed, but in Tuscaloosa County it attains thicknesses of approximately a thousand meters (McGlamery, 1955). Upper units of the Pottsville are commonly weathered to friable sands, silts, and soft clays. Paulson, Miller, and Drennen state that wide

range in electric log properties of the Pottsville formation could possibly be due to changes in degree of induration.

The Pottsville formation in Alabama, predominantly alternating beds of marine and non-marine clastics, is characteristic of the rhythmic sedimentation of cyclothems as described by Spencer (1968). Several theories proposed to explain cyclothem deposition include: Intermittant basinal subsidance and subsequent filling with sediments eroded from adjacent land masses, 2) variations in sea level in a steadily subsiding basin, and 3) cyclical variations in climate affecting precipitation, vegetation, rate of weathering and discharge of streams (Clark and Stearn, 1968). Regardless of the ultimate cause, cyclothem deposition is indicative of transition, oscillating back and forth, between marine and non-marine environments.

<u>Coker Formation</u>

The Coker formation was redefined by Drennen (1953) to include the Cottondale, Eoline, and Coker formations of Monroe, Conant, and Eargle (1946). The Coker formation, as defined by Drennen, consists of the Eoline member (formerly Cottondale and Eoline formation) at the base and an upper unnamed member, formerly the Coker formation, at the top. The Upper Coker and Eoline members crop out in the southern portion of the study area.

Eoline Member

The Eoline member of the Coker Formation unconformably overlies the Pottsville formation and can be subdivided into a basal "sand" and an Upper "clay rich" unit. The basal sand unit ranges in thinkness from 8 to 25 meters and commonly

consists of 2-3 meters of graveliferous sand at the base. These purple and pink, disc shaped, quartzose gravels are found as large as 8 centimeters, but the average size is about 2.5 centimeters. The overlying sands, ranging in color from buff in fresh exposures to reddish orange in weathered outcrops, are medium to coarse grained, slightly micaceous and cross bedded. Drennen (1953) states that isolated grains of glauconite and borings of organisms resembling Halymenites have been found in the basal sand unit. In places, sands of the basal unit are absent, but are replaced by a dark gray, carbonaceous, lignitic clay. The carbonaceous clay frequently overlies mottled red, purple, and white illitic clays, portions of which are silty. Differences in the clays are subtle and they appear to be conformable with an indistinct gradational contact. If the basal sand is absent the basal clays commonly attain thicknesses as great as 20 meters. Basal clay, non-uniform in vertical and horizontal distribution, is also found overlying basal sands and gravels. Overlying these basal sands and gravels the clay, generally carbonaceous and commonly containing plant fossils, seldom exceeds 4 meters.

The clays in the basal sand attain great thicknesses only if the sand is absent and the clays directly overlie the Pottsville formation. No distinct contacts between the basal Cretaceous clays and the underlying Pottsville have been identified during extensive field work in the Cottondale Quadrangle. The clays grade downward into weathered portions of the Upper Pottsville. Conversely, sharp unconformable contacts have been

noted between the basal Cretaceous sand unit and the Pottsville formation.

The Pottsville surface, exposed to weathering prior to deposition of Cretaceous units, is highly irregular and deeply weathered. Differences in elevation of the Pottsville surface, within the study area, have been noted to vary as much as 15 meters. As in present transitional environments of deposition, a surface fluctuation of 15 meters can cause distinct differences in sediment type, characteristics, and distribution.

Drennen (1953) presented evidence supporting marine deposition of the basal Cretaceous sands. Evidence included sporadic grains of glauconite and borings of organisms, resembling Halyminites. Monroe, Conant, and Eargle (1946, p. 192) state that disc shaped pebbles, found at the base of the unit, are indicative of wave and tidal action on a seashore. The carbonaceous clays, however, due to the presence of terrestrial plant fossils,are indicative of continental deposition. Berry (1919, p. 18-19) described and identified plants found in the carbonaceous clays two miles southeast of Cottondale, Tuscaloosa County, Alabama (N½ of sec. 36, T 21 S, R 9 W). He stated the Pottsville formation (implying bedrock) cropped out approximately 25 feet (7.7M) lower in elevation. The 25 foot (7.7M) interval, between these two aforementioned units, consists of the mottled illitic clay previously described. Berry (1919) did not analyze the environment of deposition of individual plant localities, but in his conclusions (p. 29) gave a summation of the depositional environment for the entire Tuscaloosa Group. It is interesting to note that 37 percent of the plants identified

at the Cottondale locality were described as "strand line types." This indicates that carbonaceous clays, in the basal unit, occur on topographic highs of the Pottsville surface and were above sea level. Basal sands, on the other hand, are subaqueous and occur at lower elevations. Newton (personal communication, 1976), during field mapping in Alabama, has noted that along major unconformities, sands fill topographic lows, whereas clays commonly occur on highs. The Carbonaceous clays also, in places, overlie the Cretaceous sands. This distribution of sediments seems analogous to sub-littoral beach and tidal flat deposition along present coastlines. Clay rich tidal flats occur adjacent to shoreline, on topographic highs of the old land surface, or overlie sand accumulations of offshore bars and barrier islands. Avery (1968) states that, "Tidal flats have an imperceptible amount of relief" and "marshes subject to tidal fluctuations are formed." This diversity of depositional environments explains why in places carbonaceous clays overlie basal Cretaceous sands, while elsewhere they directly overlie topographic highs of the Pottsville surface. As would be expected, the carbonaceous clays undergo a rapid lateral facies change and grade into sands. The areal extent of these clays is difficult to predict.

Drennen (1953) and Monroe, Conant, and Eargle (1946) state that the lower Cretaceous clay is discontinuous and erratic in its vertical and horizontal distribution. Tidal flat deposition, as previously discussed, would account for the discontinuous horizontal distribution of sediments, but would not, necessarily, explain vast differences in thickness.

Difficulty in delineating a sharp contact between lower Cretaceous clays and the upper weathered Pottsville formation could be invoked as a possible reason explaining the varying thicknesses of the clays.

Paulson, Miller and Drennen (1953, p. 19-20) state that, "The Contact between the Pottsville and Coker Formations is difficult to distinguish locally because of the deep weathering to which the rocks have been subjected." As previously mentioned, in places sharp contacts exist between basal Cretaceous sands and the Pottsville, but gradational contacts occur when the basal Cretaceous unit is a clay. Also, clays of the lower Eoline attain maximum thickness only when overlying the Pottsville formation. It appears that maximum thickness of the Cretaceous clays occur when overlying the Pottsville formation, because upper weathered portions of the Pottsville are non-indurate, are frequently mistaken for Cretaceous clays, and in places are incorporated in the Cretaceous unit. The illitic clay, described above, occurring at the base of the Eoline member could possibly be weathered Pottsville. The apparent gradational contact, instead of an unconformity between the carbonaceous and illitic clays, could be explained by extensive weathering on the ancient Pottsville high prior to Cretaceous deposition. Since Cretaceous sands are subaqueous and deposited on a Pottsville low, the contact, not subjected to extensive weathering and reworking, is sharp and unconformable. Carbonaceous clays, definitely Cretaceous in age due to plant fossil identification and found overlying illitic clays, could be analogous to the carbonaceous clays overlying Cretaceous

sands. The carbonaceous clays, regardless of the underlying lithology, are approximately the same thickness, occur at about the same elevation, and contain plant fossils. If the above mentioned hypothesis were correct, field observations show the lower Cretaceous clay to be uniform in vertical thickness, but sporadic in its horizontal extent. This sediment distribution would conform to that expected with transitional tidal flat deposition.

The above mentioned hypothesis, discussed in relation to topography of the ancient Pottsville surface, helps explain the depositional environment of the lower Cretaceous unit (sand and clay) and the sporadic distribution of the lower Cretaceous clays. Attempts to substantiate or disprove this hypothesis, with irrefutable evidence, have met with little success. The following observations, however, were noted in portions of the study area: 1) A geologic section previously described as basal Cretaceous clays, was noted to be overlain by a weathered but indurate sandstone ledge, possibly of Pottsville age; 2) Possible visual distinction of the lower clay units based on differences in coloration and degree of weathering; 3) Differences in organic content of the lower clay units; 4) Jointing, present in the lower illitic clay, which is absent in the overlying carbonaceous clays.

The geologic section, exposed in a road cut, in the SW¼ of the NW¼ of sec. 36, T 21 S, R 9 W, hereafter referred to as Whippoorwill Hill geologic section, consists predominately of weathered, non-indurate, silts and illitic clays. On the east of the road a weathered but indurated ledge of

sandstone, overlying non-indurate clays, is exposed. This geologic section strongly resembles the Canyon Lakes geologic section where indurate Pottsville sandstone ledges overlie non-indurate Pottsville clays. This indurate ledge is not readily visible on the west side of the road. An undulating Pottsville surface or differential weathering could explain the disappearance of the sandstone ledge to the west. Clay sequences on either side of the road, however, appear identical and evidence tends to support differential weathering of the sandstone ledge. Two visually distinct clay units are exposed in the cut. The upper clays, massive, silty and cream colored, grade downward into massive, red and white mottled clays. Both clay units are deeply weathered. Sandstone units mapped as Pottsville formation crop out approximately 4 meters lower in elevation. Because of the similarity of these clays with the Canyon Lakes section, the stratigraphic position of distinct Pottsville units, and the presence of a weathered sandstone ledge, possibly Pottsville, overlying the clays on the east side of the road, this cut could be considered of Pottsville age. Carbonaceous clays, from which Berry collected plant fossils, are topographically higher and crop out about one half mile to the east. Underlying the carbonaceous clays is an 8 meter sequence of illitic clays similar to the clays exposed at Whippoorwill Hill.

Visual distinction, in places, can be made between the carbonaceous clays and the underlying weathered illitic clays. At best, visual differentiation is tenuous, and it does not prove the Pottsville age of the lower clays. The carbonaceous

clays, upon weathering to a deep purple, resemble the underlying reddish mottled clays. Drennen (1953), when comparing Eoline and Coker sands, mentioned the hazard of using weathering as criteria for geologic differentiation.

As previously mentioned, weathering is a possible cause for the conformably appearing contact between the carbonaceous and illitic clays. Evidence of an unconformable contact was seen in the NE¼ of the NW¼ of sec. 1, T 22 S, R 9 W. Digging along the gradational appearing contact, revealed vertical iron stone ledges which filled joints in the lower illitic clay. The iron stone-filled joints, approximately .5 centimeters wide, were abruptly truncated at the contact with the overlying carbonaceous clays. Differences in coloration of the clays, as previously mentioned, were also noted at this locality.

Identification of fossilized plant remains was considered as a possible means for age differentiation of units. Macroscopic plant fossils, confirming the Cretaceous age of the carbonaceous clays, are absent in the illitic clays. Microscopic examination of samples for palynomorphs, fossil pollen and spores, revealed no organics in the illitic clays. Either no initial preservation of organic fragments or subsequent oxidation of initially preserved remains best explains the dearth of diagnostic palynomorphs or macroscopic fossils in the illitic clays. If the illitic clays do indeed represent a Pottsville high, intensive weathering during Cottondale time would have resulted in oxidation and removal of any existing organics. However, negative fossil evidence for the illitic clays does not prove Pottsville age.

The above mentioned ideas concerning the stratigraphic distinction between the Pennsylvanian Pottsville formation and the Cretaceous Coker formation, were primarily based on field reconnaisance in the Cottondale Quadrangle, Alabama.

The maximum outcrop thickness of the upper clay unit of the Eoline member is about 40 meters. The unit characteristically consists of laminated light to dark gray illitic clays interbedded with fine to medium grained glauconitic sand.

Because of the moisture retaining capability of the interbedded sands and clays, this unit commonly remains wet due to seepage during dry summer months. Excess moisture associated with this unit could be conducive to the growth of plant species which are vulnerable to dry weather conditions. In places, massive glauconitic cross-bedded sand overlies the laminated clays. Due to the distinct change in permeability, an iron stone ledge is commonly developed along this contact. If the upper Eoline sands are absent, the iron stone ledge develops at the contact between the laminated clays of the Eoline member and the overlying sands of the Upper Coker Member. Borings of Halymenites major Lesquereux are locally present in the upper Eoline sands as are thin clay lenses and clay balls. The glauconite, difficult to distinguish, weathers to a pale yellow while the sands weather to a dark red. The laminated clays locally contain plant fossils while lignitized wood, and nodules of pyrite and marcasite are found throughout the unit.

Glauconitic sands and borings of Halymenites major Lasquereux, indicate marine deposition of the upper clay rich unit of the Eoline member. Plant fossils within some clay zones, however, tend to indicate terrestrial or transitional environments of deposition. At most places the contact between the basal and upper unit of the Eoline is conformable. The similarity of the units is indicated by their conformable contact and that both commonly consist of marine sands and transitional clays. Deposition of the upper and lower Eoline member appears to be transitional between marine and non-marine environments.

Upper Unnamed Member

The Upper Coker member, at its type locality adjacent to the Black Warrior River about 3 miles south of Coker, Alabama, is approximately 80 meters thick. Generally sands occur at the base of the Upper Coker member but occasionally Upper Coker clay immediately overlies clays of the Eoline member. Upper portions of the Coker generally consist of massive clays.

The sands of the Upper Coker member, light colored, fine to medium grained, micaceous, and highly cross bedded, at places fill channels scoured in the underlying Eoline. In the Cottondale Quadrangle the contact between the Eoline and the Upper Coker member is easily discerned and the units are lithologically dissimilar. In adjoining quadrangles, however, portions of the Upper Coker member strongly resemble laminated clays of the Eoline. Generally Upper Coker sands, where present, do not weather to as deep a red as Eoline sands. Granular siderite nodules are characteristic of the Upper Coker member.

Drennen (1953) reports that sparse amounts of glauconite have been found in this unit in Fayette County, Alabama. Rounded and angular gravels, chert and quartz, are found as lenses throughout the sands.

The most diagnostic unit of the Upper Coker member is the massive variegated red, purple, and green clays. The clay generally occurs at the top of the unit and is lithologically distinct from other Cretaceous units in the study area.

The environment of deposition of the Upper Coker member appears to be a continuation of marine non-marine deposition of the Eoline member. Drennen (1953) states that sediments of the entire Coker formation are "products of essentially continuous deposition in an expanding shallow sea." He also stated that conditions in the nearshore environment of a shallow sea were unfavorable for the development or preservation of diagnostic marine features.

Terrace and Alluvium

Terrace and alluvial deposits unconformibly overlie Pennsylvanian and Cretaceous sediments in the study area. It is beyond the scope of this report to discuss terrace levels and distribution (Szabo, 1973), but terrace gravels have been identified as high as 120 M above the present level of the Black Warrior River (Drennen, 1953). Terrace deposits range in thickness, but rarely exceed 7 meters. Recent alluvial deposits form thin lenticular deposits along the floodplains of major streams.

Terrace deposits are generally graveliferous at the base, fining upward into sands and clays. The sediments characteristically weather to a reddish orange color and are difficult to distinguish from weathered sediments of the Coker formation. Terrace gravels consist of tripolitic chert, frosted and pitted quartz, rounded and polished iron stone, and rounded Pottsville sandstone (Personal communication, Charles Wielchowsky, 1974).

Alluvial sediment description and distribution is similar to that illustrated in Weller (1960) of present day floodplains. He stated that sediments are well laminated to moderately well sorted, and range in size from fine sands along natural levees, bordering the stream, to clays in the backswamp. Decreases in grain size and sorting characteristically occur with increasing distance from the stream.

Much conjecture exists between geologists concerning the origin and environment of deposition of Pleistocene fluvial terraces. Fisk (1944) considered terrace development the result of alternating alluviation, during inter-glacial periods, and valley entrenching during glacial periods. Fisk felt that older terraces were topographically high because of isostatic uplift accompanying basinal subsidance. Quinn (1957), noting Pleistocene fluvial terraces far removed from coastal zones, felt that climatic fluctuation alone could explain terrace configuration and distribution. Graded streams would cut laterally resulting in valley widening. Underloaded streams would entrench themselves while overloaded streams would alluviate the pre-existing floodplain. Climatic variations, causing streams to oscillate

between overloaded and underloaded conditions, Quinn felt, would result in terrace development.

Regardless of the reason for terrace development, fluvial terrace sediments represent overbank and channel deposition of ancestrial streams.

Topography

The Northern half of the Cottondale Quadrangle is principally underlain by the Pottsville formation, Pennsylvania in age. The Pottsville formation, predominately indurated clastics, gives rise to the rugged topography of this area. Fine textured dendritic drainage patterns, which are indicative of mature regions in the humid cycle of erosion (Thornbury, 1969), predominate. To the south the Cretaceous Coker formation overlaps the Pennsylvanian unit. Slightly higher in elevation, less rugged, and more rounded, the hills expressed by this geologic unit represent the northern extent of the Fall Line Hills (Thornbury, 1965). Coarser drainage texture (fewer tributaries) and less rugged topographic expression indicate regional age of late maturity. The contact between the Cretaceous Coker formation and Pennsylvanian Pottsville formation marks a major unconformity and is referred to topographically as the Fall Line. The change in the degree of induration of units (Coker formation--unconsolidated and Pottsville formation--consolidated) results in a series of rapids and waterfalls along their contact. This point marked the extent of inland water transportation until construction of a series of locks and dams along the Black Warrior River.

In the study area topographically high and well rounded hills are generally underlain by sands of the upper Coker member while lower lying hills are underlain by Eoline clays. The Eoline clays also crop out along the hillsides and valley walls. This topograpic expression of geologic units is similar to that described by Stephenson (1926) in reference to the Cretaceous Eutaw formation which crops out south of the study area. Stephenson stated that "most of the area underlain by the Eutaw formation is decidedly hilly, owing to the predominance of sand, but some of the more clayey portions produce a gently rolling surface." Sand hills, steeper than clay hills, are frequently dissected by V-shaped gulleys. Clay lithologies commonly form broad flat bottom land. Fine grained material has well-developed drainage patterns, while porous material has no developed drainage pattern (Mintzer 1968). Due to lower stratigraphic position the basal Eoline sands, formerly Cottondale formation, generally crop out along valleys. To the south, the weathered Pottsville formation is exposed along Willow Swamp Creek as a direct result of downcutting and erosion. The Pottsville formation, unlike well rounded hills of the Coker formation, forms the rugged, mountainous terrain in the northern portion of the study area. To the northwest the Pottsville is overlain by sediments, predominantly sands and gravels, resulting in high flat upland areas. The flat upland areas border the Black Warrior River and increase in elevation with increasing distance from the River. The areal extent of the flat uplands suggest terrace development and is mapped as

such by Paulson, Miller, and Drennen (1962). Stow and Hughes (1976), however, have mapped some of these areas as the Upper Coker member.

Slope percent maps (Stow and Hughes, 1976) clearly depict the varied topography expressed in the study area. Extremes in topography are more pronounced to the north and northwest in outcrop areas of the Pottsville formation and overlying terrace and Coker deposits. Flat lying uplands, previously mentioned, have slopes from 2 - 6% while slopes in excess of 25% are not uncommon along steepened valley walls of the Pottsville formation (Stow, 1974). Slopes of Cretaceous outcrops to the south are less variable and are generally less than 25%. The flattest land, floodplains of streams flowing adjacent to the Black Warrior River, is found in the southern portion of the study area along Cottondale Creek.

A surficial visual examination seems to indicate slight differences in slope angle for north and south facing slopes. Differences in slope angles, resulting in asymmetrical valley profiles, have been discussed by Hack and Goodlet (1960) and summarized by Leopold, Wolman and Miller (1964). They postulate that microclimatic differences, unequal sunlight exposure of slopes depending on orientation, would result in the aforementioned asymmetrical profiles. South facing slopes, in the northern hemisphere, would have longer sunlight exposure whereas north facing slopes would be exposed for a shorter duration. Longer sunlight exposure would result in dryer slopes and hence less dense vegetative covering. Freeze-thaw sequences, overland flow, and accelerated mass wasting would be more common and

ultimately the slopes would become gently inclined. Conversely, north facing slopes would be steeper. Hillside slope configuration in the study area appears to conform to the above mentioned hypothesis concerning asymmetrical profiles controlled by microclimatic differences.

Lithology

General lithology or rock types of the geologic units exposed in the study area have previously been described above. A more detailed acquisition of lithologic ground truth data, based on field reconnaissance and the lithologic maps by Stow and Hughes (1976), was collected adjacent to and south of Interstate 65 at the Coaling, Alabama exit (see figure 2). In this same area samples were also collected and size and moisture analyses were run on the collected samples (see figure 3).

Size Analysis

On June 4, 1974, five samples were collected at each of the ten locations shown in figure 3. A total of fifty samples were collected. A systematic sampling technique was utilized at each location. Single samples were taken at a central point with each of the remaining four samples being taken a distance 100 feet from the center along a N-S and an E-W line. Samples were taken by hand auger at a depth ranging from 61 to 91 centimeters. Ruhe (1975), mentions problems in sampling that arise from the difficulty in differentiating the upper weathered soil zone from the underlying lithologic unit. Samples were taken well beneath the surficial organic zone in an attempt to alleviate this potential problem.

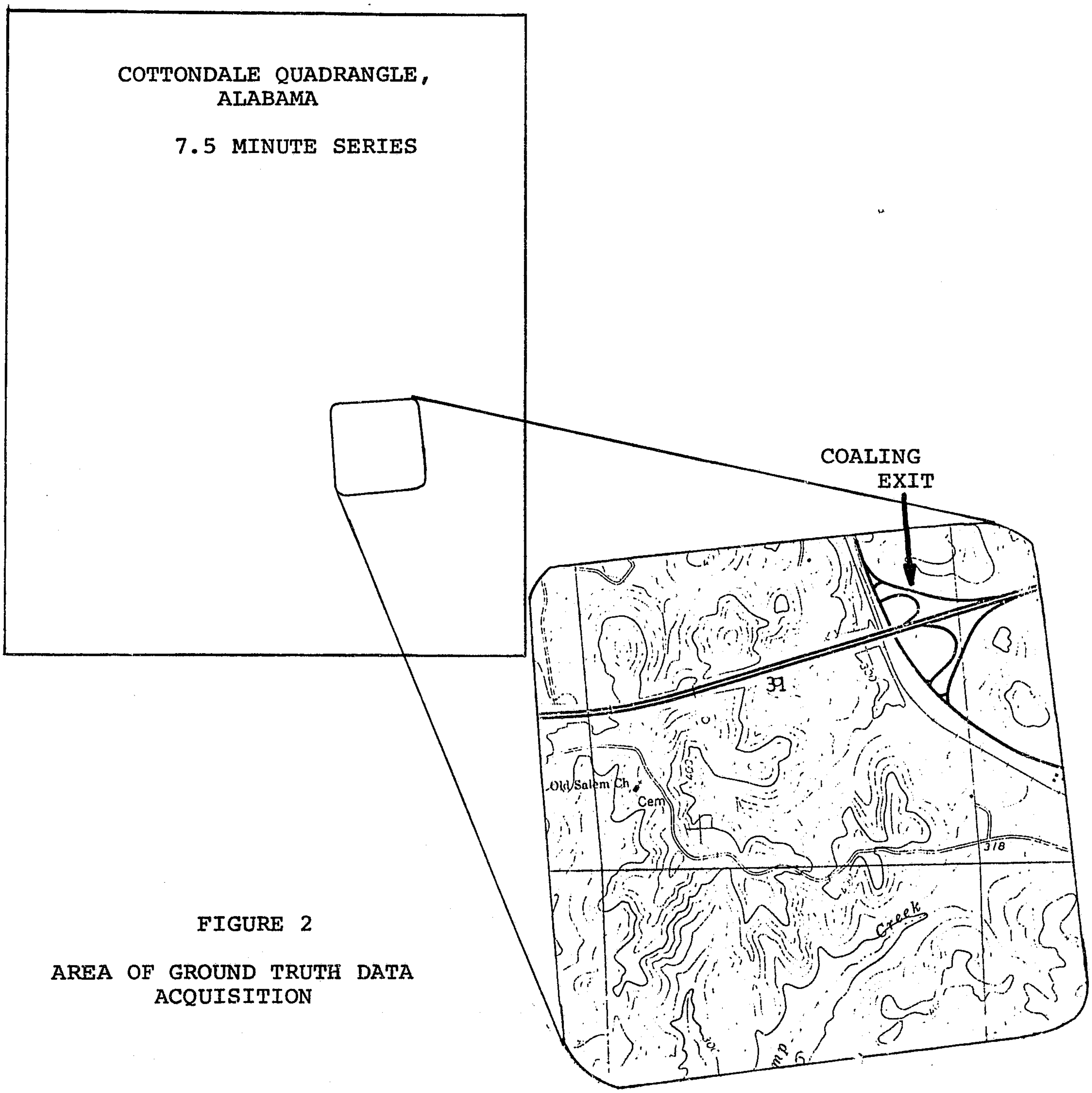

FIGURE 2

AREA OF GROUND TRUTH DATA ACQUISITION

FIGURE 3

SAMPLING LOCATIONS WITHIN AREA OF
GROUND TRUTH ACQUISITION

The following sieve and pipette analyses were conducted according to guidelines in Folk (1974) and Royse (1970). After mixing in a milkshaker for one minute the samples were wet sieved, through a 0.062 mm screen, separating sand size particles from the silt and clay sizes. Subsequent dry sieving of the sand size particles, in a rotap machine for ten minutes, further categorized the sand into coarse, medium and fine sizes. The fine particles separated from the sands by wet sieving were analyzed by the pipette method. The silt-clay boundary was calculated for each sample (table 1). These percentages, however, will not be used in the final quantitative computations, because they represent size ranges and not specific grade sizes. Cumulative curves were drawn for each of the fifty samples and percentile readings were taken at Ø 16, Ø 50, and Ø 84. The Folk Graphic Mean (Mz), used because it takes into account extremes of the collected data and is also not adversely affected by skewness, was determined by using the formula--$Mz = (\emptyset 16 + \emptyset 84)/3$. See table 2 for a listing of the mean grain size of the five samples at each sampling location. The average grain size, at each of the ten sampling locations, was used later in this report in making quantitative comparisons with photographic tone.

Moisture Analysis

On June 4, 1974, five samples were collected at each of the ten locations shown in figure 3. Moisture analyses, determining percent moisture in each sample, were conducted (appendix 1). Samples were immediately weighed, then reweighed after being oven

TABLE 1

PERCENT OF SAND, SILT, AND CLAY IN COLLECTED SAMPLES

LOCATION	SAMPLE #	PERCENT OF SAND	PERCENT OF SILT	PERCENT OF CLAY	AVERAGE PERCENT FOR EACH LOCATION SAND	AVERAGE PERCENT FOR EACH LOCATION SILT	AVERAGE PERCENT FOR EACH LOCATION CLAY
1	1	53.34	22.61	24.05			
	2	30.12	19.62	50.16			
	3	69.30	28.36	2.34	50.04	24.00	20.94
	4	57.39	26.31	16.30			
	5	65.03	23.11	11.86			
2	1	60.20	27.30	12.50			
	2	56.54	20.98	22.42			
	3	69.65	18.49	11.86	64.91	20.04	15.03
	4	67.59	14.56	17.85			
	5	70.56	18.87	10.52			
3	1	34.16	32.24	33.60			
	2	69.73	9.54	20.73			
	3	63.65	27.15	10.18	59.82	22.69	17.48
	4	61.33	24.96	13.71			
	5	71.22	19.56	9.17			
4	1	27.80	19.02	13.12			
	2	63.32	10.05	26.63			
	3	77.91	10.83	11.26	69.85	16.19	13.95
	4	70.10	18.92	10.99			
	5	70.13	22.12	7.74			
5	1	53.35	29.21	17.44			
	2	53.74	30.13	15.53			
	3	52.47	31.45	16.08	50.23	32.73	18.00
	4	43.33	38.14	18.53			
	5	48.27	33.12	18.60			
6	1	34.14	29.82	35.99			
	2	51.65	22.30	26.04			
	3	61.94	14.41	23.65	56.23	20.87	22.88
	4	63.69	20.58	15.73			
	5	69.71	17.22	13.01			
7	1	76.34	16.24	7.42			
	2	46.66	9.99	43.35			
	3	51.41	12.43	36.16	64.24	15.04	20.72
	4	71.80	20.44	7.76			
	5	75.01	16.11	8.89			

TABLE 1, CONT.

LOCATION	SAMPLE #	PERCENT OF SAND	PERCENT OF SILT	PERCENT OF CLAY	AVERAGE PERCENT FOR EACH LOCATION SAND	AVERAGE PERCENT FOR EACH LOCATION SILT	AVERAGE PERCENT FOR EACH LOCATION CLAY
8	1	71.06	15.24	13.70			
	2	71.92	13.24	14.84			
	3	75.45	13.31	11.24	68.99	15.55	15.46
	4	56.21	17.55	26.23			
	5	70.30	18.41	11.29			
9	1	34.83	49.11	16.06			
	2	39.01	45.60	15.39			
	3	41.89	43.91	14.13	42.31	43.09	14.59
	4	51.24	35.74	13.03			
	5	44.59	41.08	14.33			
10	1	72.99	16.11	10.84			
	2	42.54	41.13	16.33			
	3	69.68	10.79	19.52	63.11	21.55	15.32
	4	64.61	16.41	18.92			
	5	65.71	23.32	10.97			

TABLE 2
MEAN SIZE OF 50 SAMPLES AND THE AVERAGE AT EACH OF THE TEN SAMPLING LOCATIONS

LOCATION	SAMPLE #	MEAN GRAIN SIZE (Ø)	AVG. MEAN GRAIN SIZE (Ø) FOR EACH LOCATION
1	1	4.77	
	2	6.46	
	3	3.47	4.67
	4	4.54	
	5	4.13	
2	1	4.03	
	2	4.51	
	3	3.94	4.10
	4	4.36	
	5	3.68	
3	1	5.87	
	2	4.62	
	3	4.27	4.54
	4	4.24	
	5	3.72	
4	1	4.03	
	2	4.42	
	3	3.42	3.89
	4	3.98	
	5	3.60	
5	1	4.72	
	2	4.76	
	3	4.80	4.83
	4	5.00	
	5	4.88	
6	1	5.91	
	2	4.78	
	3	4.73	4.78
	4	4.49	
	5	4.01	
7	1	3.42	
	2	5.32	
	3	4.83	4.11
	4	3.48	
	5	3.51	

TABLE 2, CONT.

LOCATION	SAMPLE #	MEAN GRAIN SIZE (Ø)	AVG. MEAN GRAIN SIZE (Ø) FOR EACH LOCATION
8	1	4.42	
	2	4.39	
	3	3.58	4.11
	4	4.47	
	5	3.71	
9	1	5.31	
	2	4.76	
	3	4.74	4.79
	4	4.22	
	5	4.90	
10	1	3.66	
	2	4.99	
	3	4.27	4.21
	4	4.18	
	5	3.94	

dried over night at 100^{o}C; moisture percent was then determined. Sample spacing was the same as for the grain size analyses. An additional 50 samples were collected on a later date for comparison of the moisture-bearing properties of different lithologies at different times of the year. During one of these times, the week of June 4th, rainfall was minimal; a heavy day-long rain fellprior to collecting during the week of October 12; no official record of this rainfall is available. The increased precipitation for the October 12 week is reflected in Table 3, which indicates that the moisture content of the October 12 samples is consistently higher than the June 4 samples. These moisture data will later be quantitatively compared to tonal quality of the photographs.

Vegetal Analysis

Detailed vegetal analysis of eight tree stands was conducted. Five of these tree stands were located in the above mentioned area (figure 4), while the remaining three were located outside the study area. Table 4 contains data on the location, slpoe orientation and underlying lithology of each site. Tree species data were collected by the point center quarter method (Cottam and Curtis, 1956). This method involves a sample point as the center of a Cartesian co-ordinate system with the closest tree, greater than four inches in diameter at breast height in each of four quadrants, chosen as the sample tree. Distance to the sample tree, diameter of the tree and species of the tree were noted. The sample point was then moved 20 paces along a compass line. In one dense alluvial bottomland, however, the spacing was only 10 paces. Sampling

TABLE 3

AVERAGE MOISTURE PERCENT IN SAMPLES TAKEN ON JUNE 4, AND OCTOBER 12, 1974, AT EACH SAMPLING STATION

LOCATION	AVERAGE MOISTURE % IN SAMPLE	
	June 4, 1974	Oct. 12, 1974
1	14.64	17.32
2	11.15	16.36
3	12.20	14.54
4	11.63	12.59
5	19.20	25.90
6	17.43	21.43
7	9.88	14.13
8	12.75	15.95
9	12.40	17.45
10	11.55	16.18

TABLE 4

SITE LOCATIONS

Site #	Location	Slope Direction	Soil Type
1	Sec. 5, T22S, R8W	-----	alluvium
2	Sec. 31, T21S, R8W	south	sand
3	Sec. 31, T21S, R8W	north	sand
4	Sec. 31, T21S, R8W	north	clay
5	Sec. 1, T22S, R9W	north	clay
6	Sec. 1, T22S, R9W Sec. 6, T22S, R8W	south	clay
7	Sec. 27, T21S, R9W	-----	Pottsville
8	Sec. 9, T21S, R9W	north	Terrace

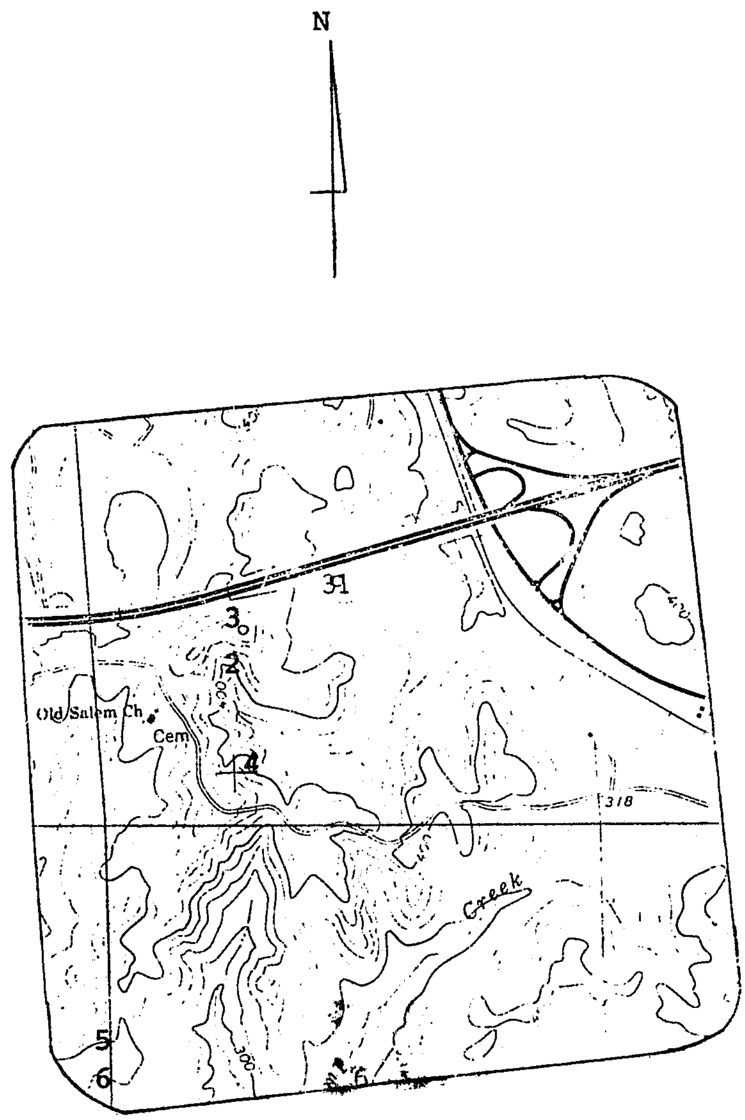

FIGURE 4

LOCATION OF THE FIVE TREE STANDS WITHIN THE STUDY AREA WHERE DETAILED VEGETAL ANALYSIS WAS CONDUCTED.

in the four new quadrants, from the new sample point, was the same as discussed above.

After collecting data, the number of trees by species was determined for each site (appendix 2). The importance values for each individual tree species was also determined for each locality (see appendix 3). The importance value (I.V.), ranging from 0-300, is the sum of the relative density, relative dominance, and relative frequency of the tree species. If no trees of a particular species were encountered its I.V. would be zero, whereas, an I.V. of 300 would indicate all trees in the area were of the same species.

Computation used for determining importance values of tree species are as follows:

$$\text{relative density} = \frac{\text{\# of individuals of a species}}{\text{total \# of individuals of all species}} \times 100$$

$$\text{relative dominance} = \frac{\text{total basal area of a species}}{\text{total basal area of all species}} \times 100$$

$$\text{frequency} = \frac{\text{\# of points at which a species occurred}}{\text{total number of points in the sample}}$$

importance value = rel. density + rel. dominance + re. frequency

See Cox (1967) for more information concerning importance values.

Mathematical comparison of the different tree stands involved using Sorensen's Index of Similarity - IS_s (Mueller, Dombois and Ellenber, 1974) and the Average Multiple "M" (MacAuthur, 1972). Both methods determine the shared species in common between different stands but the average multiple "M" also considers the number of individuals of each species.

Equations used for computing these values are as follows:

$IS_s = (2C/(A+B))$ A = # of species in area 1
B - # of species in area 2
C = # of species common to both areas 1 and 2

$$"M" = \frac{2}{1 + 2\,P\,Q}$$ P_i = # of individuals of species i found in area 1

$$\frac{iQi}{P_i^2 = Q_i^2}$$ Q_i = # of individuals of species i found in area 2

Sorenson's Index of Similarity ranges from 0 - 100. The value is 100 when both stands are identical in species composition and 0 when no species are in common. The average multiple "M" ranges from 1 - 2 with a value of 1 implying identical stands and a 2 value implying no species in common. See appendix 4 for a comparison of the different tree stands using Sorensen's Index of Similarity and the Average Multiple "M". Care must be taken when comparing one value to another since there are no statistical means for determining a level of significance.

Conclusions concerning the correlation of flora and lithologies would be more valid if the community at each site represented either the climax community or if all the communities were at the same seral stage. Additionally if the communities represented climax communities then the results would be consistent over time as well as space since climax vegetation and flora are self perpetuating. Successional communities are transitory, being superseded by communities of different composition and/or structure as time passes (Oosting 1956, Odum 1971).

All but one, the Pottsville, of the areas sampled were of the same approximate age in terms of succession. Although none

of the areas sampled represented a climax community in structure, all but the Pottsville exhibited the floristic tree composition of the climax (Harper, 1943).

Importance Value-Sites 1-8

Site 1, Alluvium

The alluvium site is occupied by the floodplain of an intermittent stream. The habitat can best be described as a black gum swamp. Although the stream does not flow in late summer, except after heavy thundershowers, the surrounding soil remains wet yearround.

Twelve species were recorded at this site. Black gum (I.V. = 126.69) was the most characteristic species of the site. Only one other species, sweetgum, had an importance value exceeding 50. The canopy foliage provided nearly 100% cover while the ground between trees was, for the most part, bare. Of all the sites examined the alluvium site supported the densest stand of trees, equivalent to 1140 trees per hectare.

Site 2, Sand - South Facing Slope

The south facing sand slope supported an open, dry pine woods. The tree density, equivalent to 599 trees per hectare, was the lowest encountered with the exception of the recently disturbed Pottsville site. The sand south facing slope also exhibited the lowest species richness of the eight sampling sites, there being only seven species recorded. Longleaf pine and loblolly pine were at the top of the importance value rankings. Longleaf pine appeared in only one other area sampled, the sand north facing slope, and hence may be of value as an indicator of sand lithologies. Black jack oak exhibited the

highest importance value among the broadleaf species present and was the only species other than longleaf pine and loblolly pine to have an importance value in excess of 50.

Although there was evidence that cattle were free to roam in this area the large size of the trees and the absence of stumps were judged to be indicative of a long period of relatively minor disturbances by man and/or his animals.

Site 3, Sand - North Facing Slope

The sand north facing slope sampling site was contiguous with the sand south facing slope, but in terms of aspect, species composition, and species richness the site was more similar to most of the other sites than to the south facing slope. Although the rank order was not identical, the same three tree species head the sand north facing slope and the clay south facing slope importance value lists. These three species, post oak - black jack oak - scrub pine/shortleaf pine, are characteristic of somewhat dry soil conditions. Dry south facing clay slopes, due to slope exposure and the well drained sandy north facing slopes, could have similar moisture conditions and hence similar stands. Sandy south facing slopes would be dryer and would, therefore, be less dense and could support different vegetative types (see site 2).

There was no evidence of recent disturbance in the area. Tree cover was close to 100% and the ground was covered with a thick layer of leaf litter. Tree density was the equivalent of 642 trees per hectare. Of the twelve species encountered, post oak exhibited the highest importance value (I.V. - 110.80).

Black jack oak was the only other species to have an importance value in excess of 50.

Sites 4 & 5, Clay North Facing Slopes

Mixed oak-hardwood stands occupied the clay north facing slopes. These areas exhibited the greatest species richness among the sites investigated. Fifteen species were recorded in site 4 and sixteen in site 5.

Unlike the previously discussed sites no one particular species dominated to the extent of having an importance value in excess of 100. The most pronounced dissimilarities between the two sites were: 1) chestnut oak which, although absent from site 5, ranked high in importance value in site 4; and 2) the marked difference in importance value for scrub pine - shortleaf pine between the two sites. Pines normally assume dominance earlier in the seral sequence that do hardwoods. However, the scrub pine - shortleaf pine trees in these areas were small trees, much younger than their neighboring hardwoods. This situation would seem to indicate that the pines became established in the wake of restricted local disturbances which apparently have occurred more frequently in site 4 than in site 5. In spite of the presence of chestnut oak and the high importance value of scrub pine - shortleaf pine for site 4, these two sites showed the greatest similarity of all sites sampled (See Results: Sorerson's Index of Similarity and Average Multiple "M").

The densities for the two sites were 623 (site 4) and 825 (site 5) trees per hectare. Canopy cover was nearly 100% at both sites. The gound was covered with a thick layer of leaf litter.

Site 6, Clay - South Facing Slope

The clay south facing slope supported a mixed hardwood-pine stand. The site was contiguous with the clay north facing slope (site 5) and the stands appeared to be of approximately the same age. The presence of black jack oak, a species indicative of dry conditions, at the top of the importance value ranking is unlike the situation on the clay north facing slope sites. The presence of black jack oak is probably caused by dryer condition, as compared with north facing clay slopes, on the southern slope. The stand density was the equivalent of 692 trees per hectare. The canopy cover was nearly 100%. A thick layer of leaf litter covered the ground among the trees.

Site 7, Pottsville

This area, sampled because the stand appeared to have been seeded naturally will probably prove of little value in delimiting the Pottsville because it represents a mid-successional stage. The importance value for loblolly pine was 139.51, the highest value recorded for any species or group whose importance value exceeded 50.

The canopy was incomplete. Ground among the trees was covered by grasses, honeysuckle, other herbaceous plants and/or needle and leaf litter.

The size of most of the trees indicated that the land's prior usage was probably abandoned withing the past fifteen to twenty years. The density was equivalent to 745 trees per hectare.

Site 8, Terrace

The terrace sampling site was on a north facing slope. A mixed hardwood stand occupied the site. The presence of oaks and hickories of large diameter, 40-60cm, was an indication that major disturbances have not occurred recently. However, minor disturbances were continuing and were probably the result of the location of this site which was bounded on three sides by housing. Southern red oak exhibited the greatest importance value. With the exception of black cherry, Prunus serotina, all species found in this stand were found in at least one of the seven other sampling sites. Vegetative types would probably vary for terrace deposits due to the possible range of lithologic types.

Sorenson's Index of Similarity Comparisons

The eight sampling sites necessitated 28 applications of Sorenson's Index of Similarity (IS_s). As one would expect no two stands were identical, i.e. $IS_s \neq 100$. The value obtained ranged from 41.67 to 83.87 (Appendix 4).

The low similarity between the stands occupying the sand south and north facing slopes, $IS_s = 52.63$, indicates that the foliar reflectance of stands on sand lithologies will probably differ significantly depending upon the slope direction.

The highest IS_s value, 83.87, was obtained from the comparison of the clay north facing slope (site 5) with the clay south facing slope. The clay north facing slope (site 4) and the clay south facing slope showed an IS_s value of 76.92. This evidence indicates that for clay lithologies, in contrast

to sand lithologies, slope direction is not as critical a factor in determining the presence or absence of a given species. These vegetative distributions are probably controlled by moisture. Clay lithologies retain moisture and are probably not as affected by drying due to slope exposure as are sand lithologies. Foliar reflectance patterns for stands on clay lithologies should be highly similar regardless of slope direction.

A high IS_s value, 69.56, was also calculated for the sand north facing slope--clay south facing slope.

Average Multiple "M" Comparisons

The interpretation of the results of the Average Multiple "M" comparisons are similar to those derived from the importance value rankings and from the Sorenson's Index of Similarity comparisons. Close similarity exists between the clay sites, between the clay south facing slope site and the sand north facing slope site and between the clay south facing slope site and the sand south facing slope site. With the exception of the clay south facing slope - sand south facing slope pairing, these are the same pairings that showed the greatest degree of similarity according to Sorrenson's Index of Similarity and thus corroborate the conclusions drawn from it. Later in the report the vegetal analysis was subjectively compared with percent light transmission of select areas on multispectral photographs.

PROBLEMS CONCERNING REFLECTANCE SURFACE

Any photo interpretor attempting to differentiate lithologies in a humid region must be aware of several potential problems concerning reflectance surfaces. Recognition of these problems must be a subjective part of any analysis and therefore necessitates visual interpretation. Problems encountered are: 1) difficulty in field differentiation of lithologic contacts due to weathering and due to rapid lateral and vertical facies changes, 2) reflectance intensities controlled directly and indirectly by topography, 3) variables affecting natural vegetal zonation, and 4) man-made vegetal land-use patterns.

As previously discussed, weathering of the upper Pottsville surface and subsequent deposition of Cretaceous units complicate geologic mapping in the study area. Lithologies vary within short distances both horizontally and vertically. Since field lithologic differentiation is, at best, quite difficult in portions of the study area, one could hardly expect that large scale lithologic maps, based exclusively on vegetative zonation reflectances collected by remote sensors, would have a high degree of accuracy. For this reason field reconnaisance must be combined with photo interpretation.

Topography has both a direct and an indirect effect on the reflectance surface. Direct effects are caused by slope inclination which controls the resulting reflectance on incident light rays. According to the Law of Reflection the angle of incident light rays is equal to the angle of the reflected light rays. Light rays reflected off of flat surfaces, assuming

overhead illumination, would bounce straight back 180°. Aerial sensors would receive maximum reflectance over flat surfaces and the resulting photographs would appear light toned. Rugged, irregular terrain would result in light being reflected at various angles and therefore aerial sensors would receive less illumination. All other factors being equal, photographs taken over rugged terrain would appear darker toned than those taken over flat lying areas.

Topography also has secondary effects on the reflectance surface by controlling vegetative type. Vegetative types are controlled, in part, by slope orientation. As previously mentioned, south facing slopes are dryer than north facing slopes. This moisture difference commonly causes a difference in vegetal type and vegetal density. Vegetal zonation due to slope orientation could possibly mask vegetal zonation due to lithologic differences.

The numerous variables affecting natural plant zonation must be considered. With the exception of some of the lowest forms of plant life, no one plant is distributed over the entire globe. The internal organization of plants restrict and confine their growth within certain limits. "It grows and reproduces its kind in those places where conditions of climate and soil are most favorable for its particular needs" (Harper, 1913). According to Mohr (1901), factors controlling plant distribution can be divided into universal (primary) factors and local (secondary) factors.

Universal Factors (primary)

Air, light, heat, and moisture are considered as factors

which restrict plants to broad regional or universal zones. Regional zones, relying mainly on heat (latitude) and moisture (precipitation), were first devised by Alexander von Humboldt and ultimately gave rise to the science of plant geography. By 1894, C.H. Merriam established regional plant zones on the basis of the amount of heat required for the germination, growth, and ultimate production of seeds of different plant species. Since regional zones are broad generalized areas, they will not be considered further and will not constitute a part of this study.

Local Factors (secondary)

Altitude, topography, proximity to large bodies of water, and the chemical and physical character of the soil and subsoil are factors which are important in confining plants within narrow local boundaries. The chemical and physical character of the soil and subsoil controls the surface and subsurface drainage (moisture) and, according to Harper, must be considered as one of the most important of the seconday factors influencing local plant distribution. Daubenmire (1959) states that soil texture is an important factor controlling plant distribution because it effects root penetration, water infiltration and rate of movement, water holding capacity, soil fertility, soil aeration, and soil temperature. Within a localized climatic region chemical and physical soil variations are often controlled by differences in parent material and topographic position (Oosting, 1956). McCalley (1886) reports characteristic vegetal types associated with different

lithologies of the Drift (Cretaceous) deposits and of the Coal Measures (Pennsylvanian-Pottsville Formation) of Alabama. Oosting (1956) further states that "it is not surprising that vegetation types and soil types are closely related." To the geologist, the term subsoil refers to lithology. The physical character of different lithologies, whether the material is sand, silt, clay, or indurated bedrock, and also the chemical nature of the material affects quality, quantity, and rate of flow of water through the material. It is this distribution of mineral constituents and moisture which probably has the greatest effect on plants in a localized area. Oosting (1956), states that, "Soil water probably affects plant growth much more commonly than any other soil factor." According to Ralph Chermock (1975), it is the dry season that restricts plants to localized environments. Many plants can survive an excess of moisture, but if conditions become dry, the plants become segregated according to the physical and chemical conditions of the soil. Moisture loving plants would be restricted to clay rich zones of high moisture. Each of these localized zones would probably exhibit plants which are absent or at most are more or less intensely represented than in other zones. Zonal differences in a localized area would probably be subtle and difficult to differentiate. Since localized zones were dependent upon altitude, topography, proximity to large bodies of water, and, more importantly, upon the chemical and physical character of the soil and subsoil, an insight into the plants environment of development could be gained by mapping or

delineating localized plant zones. If one of the above mentioned factors tends to predominate then plant zoning could result in the identification and delineation of that particular factor. The vegetal analysis will be compared with the lithology of the area, since Harper (1913) considered soil and subsoil (lithology) characteristics as one of the most important factors controlling local plant zoning.

Other variables concerning vegetal reflectance surface include: 1) successional stage of maturity and 2) proximity to seed sources. According to Cannon (1974) as tree stands go through different successional stages their reflectance and emittance properties change. Also, proximity to seed sources could control vegetal zonation. Johnson and Sellman (1974) summarize the problems concerning vegetal zonation by stating, "Since species composition is controlled by a number of interacting factors, including site quality, stand history, stage in succession, and proximity to seed sources, it is possible for species that are expected to be primary components to be reduced to a minor representation or even to be absent. It also is possible for species to appear as primary components which normally would be minor components or absent. These aberrations cannot be avoided." Also Johnson and Sellman (1974) mention the problem of vegetal zonation associated with high moisture content of colluvial material bordering steep slopes, thus masking underlying lithologies. Since the above mentioned problems can override or mask vegetal zonation controlled by underlying lithologies it is mandatory that photo-interpretation be combined with field reconnaisance for more accurate results.

Man-made vegetal land use patterns must also be recognized and delineated on aerial photographs. Since this study has been concerned with developing a lithologic signature based on natural vegetal distribution, artificially revegetated surfaces must be recognized and eliminated from further consideration.

PROBLEMS INHERENT WITH IMAGERY

Problems complicating photo interpretation, other than those previously mentioned concerning the reflectance surface, are often inherent with the imagery. Inherent problems include shadows, due to sun angle, prevailing weather conditions at time of flight, season of flight, and also parallax due to increased viewing angle along scene margins. If possible these variables must be held constant. Variance of these conditions may result in photograph tonal differences which could cause differences in interpretation.

Photograph shadows are caused by the sun's rays striking the earth at an oblique angle. Shadows would be larger during the early morning and late afternoon and would possibly have the tendancy to mask vegetal reflectances. Ideal time of flight would be when the sun is overhead and shadows are at a minimum.

It should also be noted that photograph tone varies within single frames due to varying intensity of reflected light detected by the sensor. The center of the photograph receives maximum reflectance instensity and is lighter in tone than the photograph edges. According to Watson (1972) improper identification of features becomes more pronounced along the edges

due to greater view angles. This could be due to tonal variances or to parallax which causes distortion of features along scene margins.

Atmospheric weather conditions control light intensity reaching the earth's surface. Cloud cover diminishes incoming electromagnetic radiation and therefore results in dark toned photographs. Areas of the photo that typically appear dark are masked by this overall photographic tone. Optimum conditions of flight are on clear cloudless days. On clear days photographs are lighter toned and dark areas of the photo "stand out" against the light background. Also, photos should be taken during a time of low rainfall. Abundant rainfall could result in ubiquitous plant vigor which, in conjunction with saturation of the reflectance surface, would give a uniform reflectance to the remote sensor. If conditions are dry moisture variences would be controlled by soil and lithologic types.

This variation of soil moisture could cause similar plants to exhibit different degrees of plant vigor and growth. Differing plant vigor would show up as different tonal values on aerial photos and could be a means for lithologic differentiation. Also, moisture differences could cause vegetative zonation as previously discussed.

Optimum season of the year for flight time varies depending upon what is to be studied from the aerial photo. Photos used for topographic mapping should be taken in the winter after the leaves have fallen. Photos used by foresters should be

taken in the late spring or late fall (Avery, 1962). In late spring, after all trees have produced some foliage but prior to maximum pigmentation, reflectances vary depending on the type species present (Johnson and Sellman, 1974). Avery (1962) stated that this time of year was best for collecting infrared imagery for vegetative differentiation. He also states that studies in the Lake States show that panchromatic film yields the best results in late fall. About two weeks before trees shed their leaves there are differences in foliar color which is recorded by the photograph. The present study, concerned with the correlation between vegetation and underlying lithologies, utilizes multispectral photographs taken in late spring.

ANALYSIS OF MULTI-SPECTRAL IMAGERY

The four multispectral bands were visually analyzed and tonal responses, in relation to surface features, were explained. Optimum enhancement techniques were also determined.

Band Selection

Generally electromagnetic radiation with short wavelengths is attenuated and scattered by atmospheric particles while longer wavelengths are more readily transmitted. Since less radiation of the blue band range penetrates the earth's atmosphere the resulting photos are darker than those of other bands. Also, the photos are homogeneous and lack contrast due to this scattering. Tanguay and others (1969) state that both vegetation and water bodies show the same dark gray tone and cannot be differentiated from surrounding land. High reflectance from asphalt surfaces cause road systems to appear light.

The green band, showing more contrast than the blue band, appears more useful for visual analysis. Avery (1968) states that the green band should be ideal for differentiation of vegetative types. Differing tones of green for various vegetation are recorded by the sensor as varying shades of gray. Water is not readily differentiated from land and appears as an intermediate gray tone. Cultural and man-made features are prominent because of their varying reflectances (in relation to vegetation) in the green band.

The red band is spectrally similar to the green band (Tanguay and others, 1969). Drahovzal and others (1976) state that, "the red band prominently exhibits cultural features, such as roads, power lines, urban areas, and cleared land--forest land boundaries." These observations by Tanguay and others (1969) and Drahovzal andothers (1976) are confirmed by visual analysis; however, the red band seems to show more contrast than the green band.

The infrared band shows the most contrast of the bands examined. Topography and water bodies are prominent features on this band (Pestrong, 1969). An advantage of the infrared band over the bands of the visible spectrum is that infrared radiation can more readily penetrate fog or haze and the band is not as adversely affected by poor weather conditions.

Since vegetation is primarily responsible for photograph tone within the study area, the vegetal characteristics which cause reflectance in the visible and infrared range must be analyzed. Reflectance properties of single leaves are basic to the understanding of reflectances of entire plants or canopies.

Factors controlling reflectance from single deciduous leaves are: 1) pigmentation, 2) morphology (internal cellular structure) and 3) plant vigor. Pigmentation affects visible light by exhibiting strong absorption of radiation within this range of wavelengths. Different plant species contain different amounts of chlorophyll and reflectances in the green band are quite variable (Gates, 1964). High reflectance in the infrared is due to the lack of pigment absorption at these wavelengths. The incident radiation is reflected by the leaves' cellular structure. Differences in internal morphology would result in spectral differences in the infrared range. Changes in plant vigor can cause variances in both pigmentation and cell morphology. These variances would be evidenced by changes in spectral quality in both the visible and infrared ranges.

Because needles of pine trees (conifers) are finely divided they are not as reflective in the visible or infrared as are deciduous leaves. These observations might lead to the erroneous conclusion that pines always appear darker toned than deciduous trees. Density of pine stands is extremely important. Stands of low density expose more surface area which is highly reflective in the visible range.

"On a percentage basis the reflectance from a canopy is considerably less than that from a single leaf because of a general attenuation of radiation by variations in illumination angle, leaf orientation, shadows, and nonfoliage background surfaces such as soil" (Knipling, 1970). Entire deciduous canopies, like single leaves, show strong reflectance in the infrared. Canopy reflectance in the infrared is intensified

by multiple leaf layers. Infrared radiation is not only reflected from outer layers but is also reflected and transmitted upward from lower layers. Visible light, however, is reflected exclusively from surface layers.

As previously stated topography has both direct and indirect effects on the reflectance surface. Flat lying areas result in a more direct reflectance thereby causing lighter photographs. Rugged mountainous areas should be darker toned. Vegetal reflectances, however, in conjunction with topographic reflectances can give a variety of tonal responses.

Tonal Difference

Visible Light

The following observations, initially made by studying positive transparencies, are illustrated on positive prints as Plates 1, 2, 3, and 4.

Bare Areas - Good reflectance, therefore roads and bare fields show up as the lightest areas on the photographs.

Broad Leaf - Low reflectance due to large amounts of absorption by chlorophylls (dark tone). Generally associated with high moisture content (clay rich).

Planted Pines - Pines exhibit less reflectance than broad leaf vegetation. Very dense, masking ground reflectance, planted pines are generally darker than broad leaf vegetation but are not readily differentiated.

Natural Pines - Generally are controlled by sandy lithology and are found associated with black jack or scrub oaks. Because of the low density of natural pines (increasing the ground reflectance), this area appears as an intermediate gray tone. Natural pine stands are lighter toned than broad leaf vegetation and are easily differentiated. Natural and planted pine stands are easily differentiated unless the planted stands have been thinned. If thinned, there is no tonal difference between planted pine stands and natural stands. The planted pine stands can then be identified by their uniform height and symmetrical arrangement.

Water - Medium gray (not very distinctive).

Topography - Topography is not readily differentiated because topographic reflectances, when combined with lithologic reflectances, result in an intermediate gray tone. Sand generally underlies hills in the study area. Hills have a low reflectance (dark tone) while sparsely vegetated sand lithologies have a high reflectance. The two opposing reflectance values result in intermediate gray toned hills. Valleys, however, which are generally clay lithologies, support dense vegetation and have a low reflectance. Topographically low flat lying areas have high reflectance. Once again the two opposing reflectance values result in an intermediate gray tone.

Near Infrared

Bare Areas - Medium gray tone and fine textured. The tone, subject to change with varying amounts of rainfall, darkens

with increased moisture content.

Broad Leaf - High reflectance (light color), mainly due to the internal structure of the individual leaves within the leaf canopy.

Planted and Natural Pines - Pines are poor reflectors and are therefore dark toned. Planted and natural pines cannot be easily differentiated because the barren areas associated with natural pines are not as reflective in infrared as was the case in visible light.

Water - Dark toned due to absorption and little reflectance.

Topography - Topographic and lithologic reflectances accentuate each other on the infrared band causing hills to appear dark while valleys are light toned. Low reflectance on irregular topographic highs usually coincides with the low reflectance of vegetation associated with sand lithologies. Hills, therefore, are generally dark toned. Valleys, generally clay lithologies, support dense deciduous vegetation which is highly reflective. This high reflectance coincides with high reflectance from flat surfaces and results in light toned valleys and lowlands.

Note that by using a combination of visible and infrared photographs, natural pines, planted pines, and deciduous vegetation can be easily differentiated.

Enhancement Comparison

Ahlar and Protz (1972) state that tonal variances are more readily differentiated by visual interpretation than by mechanical means. If distinct features were to be identified by direct

spectral responses then automated processing of the images would be accurate and would also save time. However, since lithologic spectral responses are controlled by secondary and tertiary surface phenomena automated processing could not easily take into account the numerous variables. Such analyses by automated processing would probably be inaccurate.

Multispectral photographs were initially studied as positive transparencies. A "Richards Light Table" was used, transmitting light from below, for illuminating the photograph. Light intensity was varied until maximum contrast was obtained. Preliminary observations using positive transparencies have previously been discussed as "Tonal Difference".

Positive transparencies, while mounted on a light table, were photographed using both Panatomic-X and Kodalith negative films. The camera used for photographic work was a Cannon FTB with 50mm. lens. Ten-squares-to-the-inch graph paper was also photographed as a control grid for determining extent of distortion inherent with camera and lens. See figures 5 and 6 comparing original graph paper and control grid, respectively. No distortion was noted.

Harris (1973) discusses the use of different types of negative films, developers, and printing paper for the enhancement of images. The negative films, Panatomic-X and Kodalith, were developed by standard procedure (see Editors of the Time-Life Books, 1970) using Microdol-X as the developer. The negatives were then placed in an enlarger which transmitted light through the negatives exposing photographic paper below. Time of exposure varied depending on negative tone. Dark

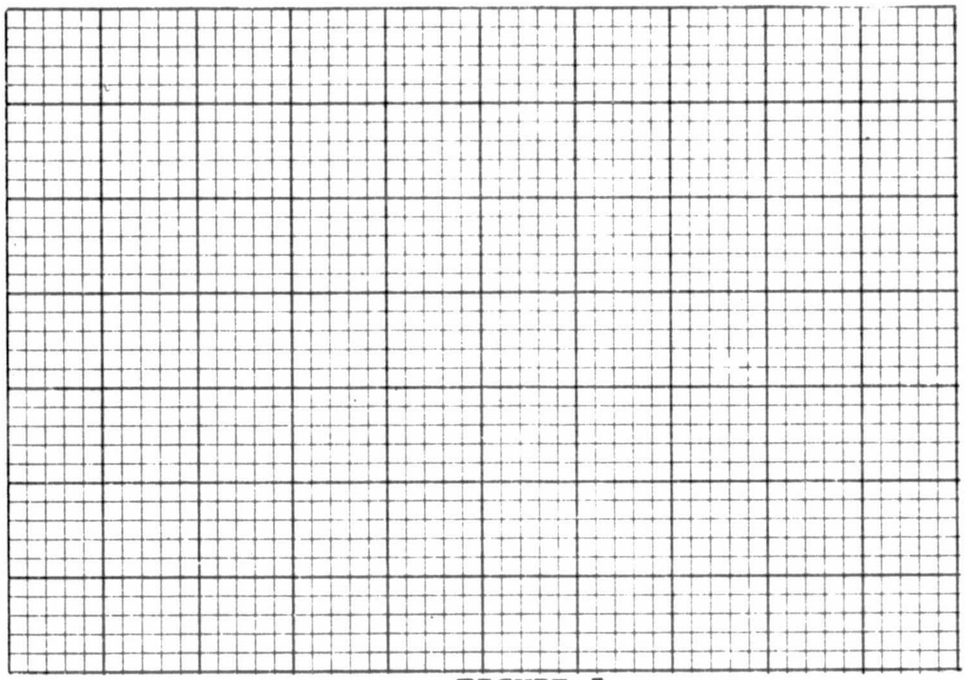

FIGURE 5

GRAPH PAPER USED TO CHECK FOR DISTORTION RESULTING FROM PHOTOGRAPHING MULTISPECTRAL IMAGES

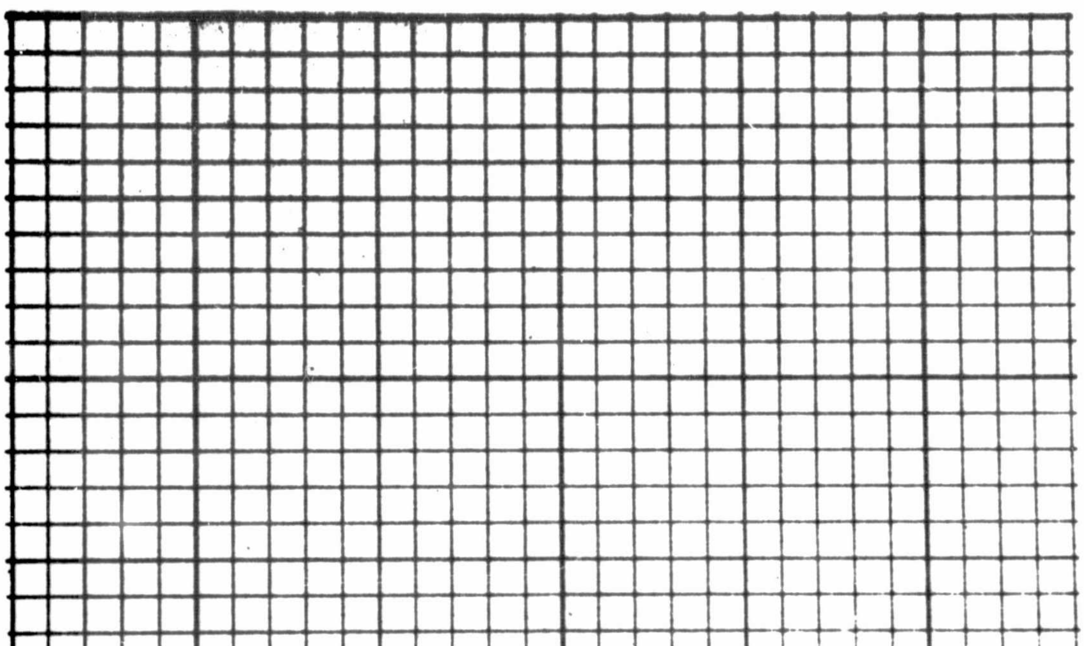

FIGURE 6

ENLARGED PHOTOGRAPH OF GRAPH PAPER (FIGURE 5) USED TO CHECK FOR DISTORTION RESULTING FROM PHOTOGRAPHING MULTISPECTRAL IMAGES

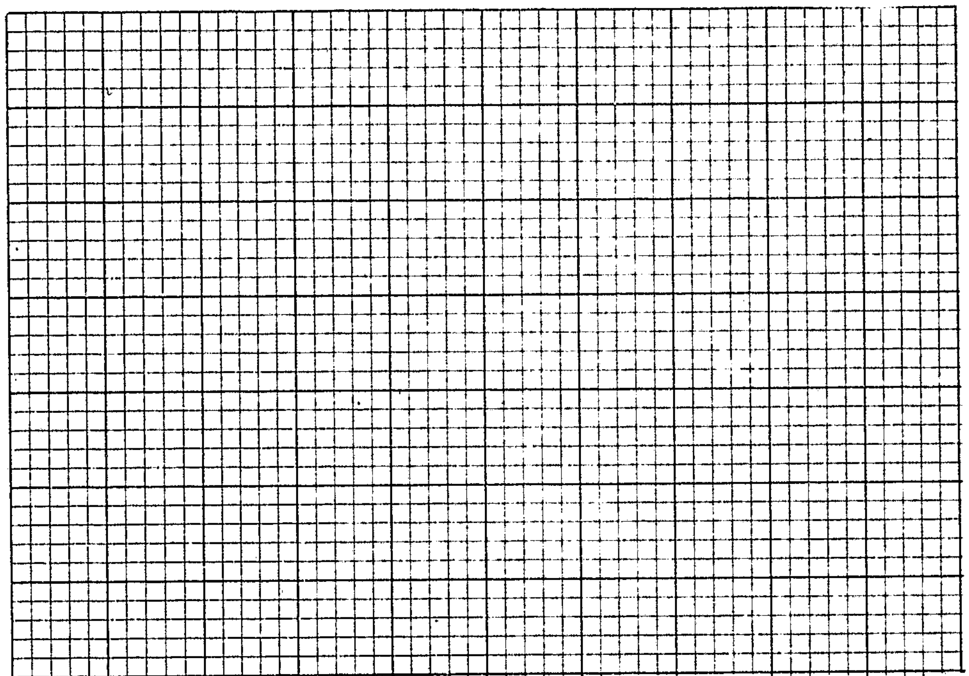

FIGURE 5

GRAPH PAPER USED TO CHECK FOR DISTORTION RESULTING FROM PHOTOGRAPHING MULTISPECTRAL IMAGES

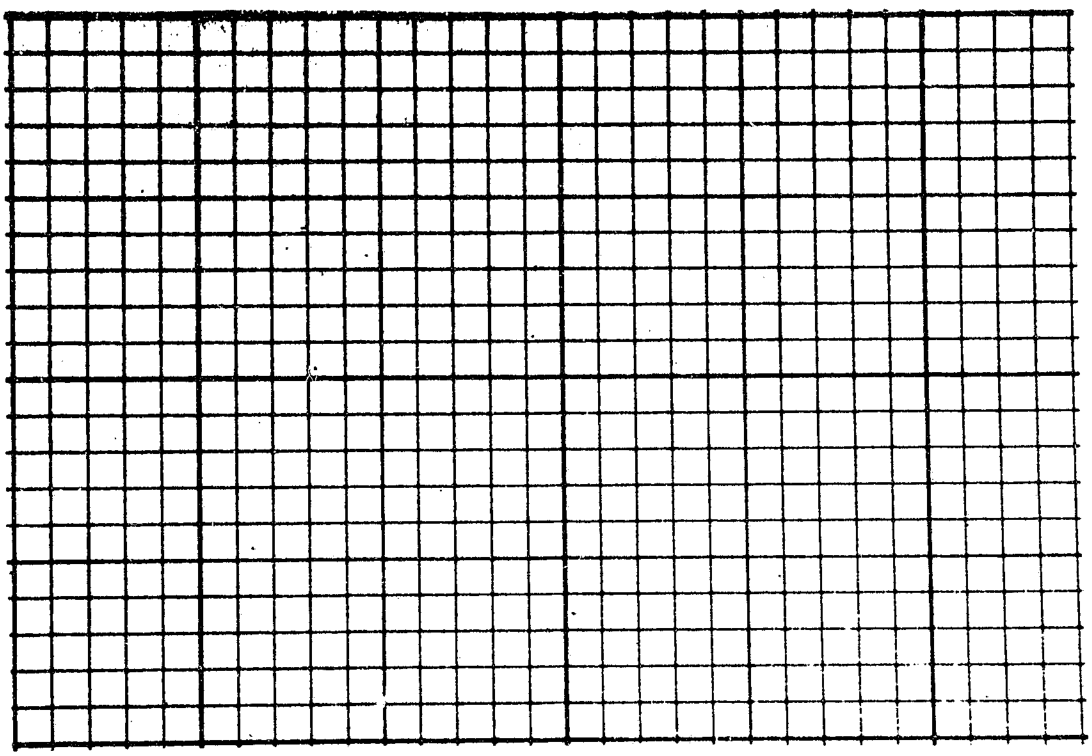

FIGURE 6

ENLARGED PHOTOGRAPH OF GRAPH PAPER (FIGURE 5) USED TO CHECK FOR DISTORTION RESULTING FROM PHOTOGRAPHING MULTISPECTRAL IMAGES

negatives required longer exposure time, whereas light negatives were exposed for shorter duration. Negative tone varied depending on quality of the original scene and also on the multispectral band that was being analyzed. As previously discussed,photographs were lighter in the center, due to direct reflectance, becoming darker around the edges. Conversely, the negatives were darker in the center and lighter around the edges. In order to compensate for this tonal difference the edges of the negative, during exposure, were covered for a short time. This difference in exposure time allowed additional light to pass through the dark central portion of the negative. A shorter exposure time was needed for the edges because this portion of the negative readily transmitted light. The end result of covering negative edges was a relatively even illumination of photographic paper, thereby, producing a more homogeneous print.

Vegetal arrangement within the scenes can also enhance tonal difference between photo center and edges. Deciduous vegetation and planted pines give dark tonal responses when photographed in visible light. If these vegetative types were restricted to scene margins their decreased reflectance would accentuate the dark tone due to increased reflectance angle along photo edges. The resulting photo would be extremely dark around the edges and lighter in the center. If the aforementioned vegetative types were located in the center of the scene and thus darken this region of the photo, the net result would be a more homogeneous print. Conversely, deciduous vegetation is a strong reflector in the infrared and, if imaged

along scene margins, would result in a homogeneous print. Deciduous vegetation restricted to the center of an infrared scene, with pines located along scene margins, would result in intensified darkening around photo edges.

A-weight polycontrast paper, sensitive to specific wavelengths of light, was used for photograph printing. Subtle tonal differences are better enhanced by polycontrast paper than by standard paper. See Editors Time-Life Books (1970) for standard photograph printing procedures. Filter #2 was used during exposure of photographic paper. Filters #3 and #4 diminish subtle tonal differences by grouping similar tones as one composite tone. The resulting number of gray tones due to this grouping is less than if filter #2 is used. Major tonal differences, however, are intensified by filters #3 and #4 and the problem of tonal variation between photograph center and edges is enhanced.

Plates 5, 6, 7, and 8 (blue, green, red and infrared bands respectively) - panatomic-X positive prints- illustrate the relationship between tonal contrast and lithologies of the area. Panatomic-X positive prints do not increase tonal contrast or better differentiate lithologies than do positive transparencies. Positive transparencies, mounted on a light table, have the added advantage of variable light intensity. However, optimum light intensity is determined, illustrating best tonal contrast, prior to photographing and subsequent printing of positives. Positive prints are easier to analyze because of their detachment and ease of orientation. They

can also be taken into the field and the surface of the photo can be drawn directly upon.

Kodalith film, like panatomic-X film, was used to photograph optimum illuminated positive transparencies mounted on a light table. Plates 9, 10, 11, and 12 (blue, green, red, and infrared bands respectively) compare tonal quality of kodalith positive prints with underlying lithologies. Like filters #3 and #4, Kodalith film diminishes subtle tonal contrast while enhancing major contrast. The film, sensitive to threshold radiation intensities, records light as a series of specific tones. If an intermediate intensity between tonal values exposes the film it is recorded as the darker tone. A lighter tone is not produced on the image until a certain threshold of radiation intensity is reached. Intermediate radiation intensities are not recorded as separate tones. The tendency to enhance major tonal contrast is illustrated by Plates 9, 10, and 11 (blue, green, and red bands respectively). These plates illustrate the problem of tonal variation between center and edges,and bands 1, 2, and 3 are of little value for photographic analysis. Plate 12 (infrared) is not as adversely affected by major tonal differences. The homogeneity concerning photo edges and center is due to deciduous vegetal arrangement around scene margins.

Although the infrared kodalith positive print (Plate 12) appears to show good contrast it is not suitable for detailed analysis. Light and dark contrast, since fewer intermediate gray tones are shown, causes the entire image to be coarse

textured. Fine textured areas, evident on panatomic-X positive prints, are not readily discernable. Since texture and tones are equally important, kodalith prints of band 4 were not further analyzed.

The four multispectral bands were printed as false or bas-relief photographs and enhancement capabilities were determined. Bas-relief prints were made by exposing photographic paper through superimposed positive and negative transparencies. The positive transparencies were slightly offset thereby enhancing linear trends perpendicular to the offset.

Positive transparencies of the four multispectral bands, as supplied by NASA, were used in making bas-relief prints. Weller (1970) recommended high contrast film for the negative transparencies. Unexposed kodalith negative film was placed under the positive transparencies and a contact negative was made by exposing and subsequent developing of the negative film. The positive and negative transparencies, exactly the same scale, were superimposed with a slight north-south offset and were placed in an enlarger for print exposure. Superimposing the positive and negative transparencies reduced tonal variations. The slight offset, however, enhanced the contact between tonal differences and showed as a straight line trend. North-south offset would enhance contacts trending east-west. Bas-relief prints of each of the four multispectral bands were printed with both north-south and east-west offsets. For visible light the red band shows better enhancement than the blue and green band and is illustrated as Plates 13 and 14.

See plates 15 and 16 for infrared bas-relief prints. Bas-relief prints do enhance linear trends; however, lithologic contacts of horizontal sedimentary rocks seldom form continuous straight lines. Bas-relief prints would prove useful when mapping geologic structures if offset direction were perpendicular to prevailing structure of the area. For lithologic differentiation, however, bas-relief prints have limited use.

Color additive viewing is an enhancement method used in the analysis of multispectral black and white positive transparencies. Color is added to the individual bands which are then superimposed to form a composite color print. An I^2S color additive viewer was used for this enhancement technique.

According to Drahovzal and others (1976), "Additive color systems usually contain four sources of light with variable intensity controls, four film holders with two-dimensional adjustment mechanisms, four, four-color filter systems (clear, red, blue, and green), an optical system that superimposes the images of the films, and a viewing screen on to which the single color composited image is projected" (see figure 7). Initially the multispectral transparencies are threaded through the I^2S viewer and are registered (superimposed) by using the two-dimensional adjustment mechanism. Light intensity can be varied and choice of blue, green, red or clear filters can be utilized for each band. All four bands do not have to be used to form a composite image. According to Yost (1972) densities (gray tones) of the same feature may vary from band to band.

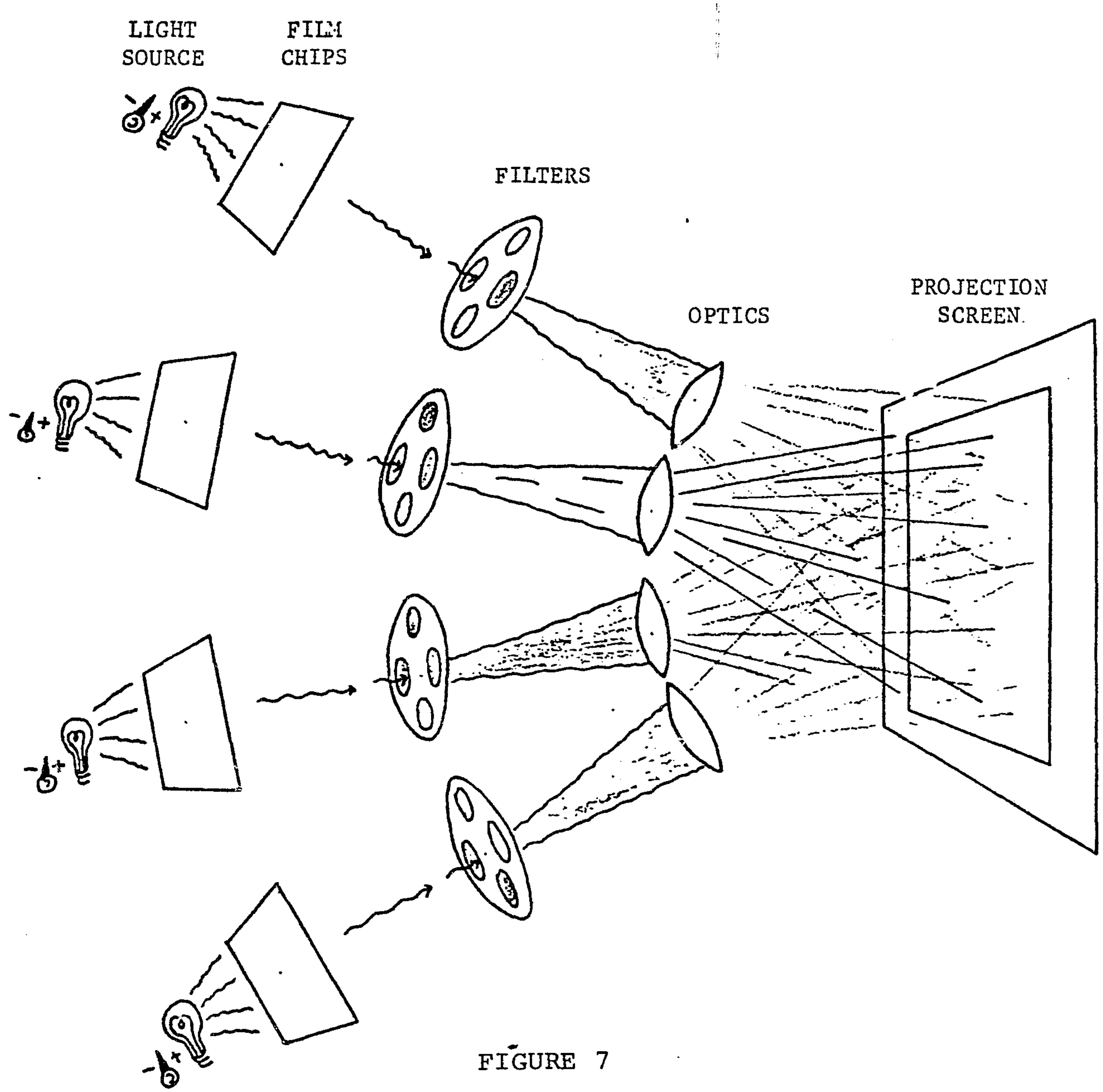

FIGURE 7

GENERALIZED DRAWING OF COLOR ADDITIVE VIEWING SYSTEM (FROM DRAHOVZAL AND OTHERS, (1976)

He states that, "this density difference is caused primarily by the selective spectral reflectance of ground objects, a fact which, in the visible spectrum, accounts for the apparent color of ground objects. Color is an effective means of discriminating density differences between similar images" (features) "which appear on sets of multispectral negatives." Properly adjusted the color additive viewer combines characteristics of each band into one composite color print. Color differences correspond to tonal differences between the original black and white bands. Gray tones, on the color composite, correspond to areas of no tonal variation between bands. These areas transmit equal amounts of blue, green, and red light thereby blending together forming a gray tone.

If color combinations of blue, green, red, and white were used with the blue, green, red, and infrared bands respectively a true color composite results (Yost and Wenderoth 1967). Color combinations of blue, green, and red used with green, red, and infrared bands, respectively, produce a false color composite. This color combination is the same as that of color infrared imagery. Five different scenes were viewed and over seventy different color combinations were photographed from the I^2S viewing screen. Ektachrome CPS film was used for photographic work and was processed by Helms Color Service in Birmingham, Alabama. After visual analysis of color slides, 5 X 7 color prints were made of composites illustrating the best topographic and vegetative correlations. Table 5 lists color combinations showing good color contrast of topographic differences. Generally white light through the green band with

TABLE 5

COLOR ADDITIVE VIEWING COMBINATIONS WHICH EXHIBIT TOPOGRAPHIC DIFFERENCES

FILTER COLOR	BANDS			
	Blue	Green	Red	Infrared
1	None	Green	None	Red
2	Green	White	Green	Green
3	Blue	White	Red	Red
4	Green	White	Red	Blue
5	Blue	White	Red	Blue
6	Blue	White	Green	Green

various color combinations for the blue, red, and infrared bandsgives the best results (see Plate 17). The green multi-spectral band, visually similar but darker than the red band, shows subtle tonal variance due to topography. White light transmitted through the green band intensifies this topographic variance. The infrared band should be used in conjunction with the green band because of distinct tonal differences of topography between the two bands. The infrared band must utilize a different color than the green band but can transmit either blue, red, or green light. As long as the blue and red bands do not transmit white light, their filter color is unimportant. The red multi-spectral band, lighter in overall tone than the blue band, transmits more light if the white filter is used and topographic variations tend to be "washed out." Conversely, if the blue band, darker overall, were illuminated by white light it would not transmit sufficient light and would not show topographic variations.

Cultural features are distinct when white light is used with the blue band and different color combinations are used with the green, red, and infrared bands (see Plate 18). The blue band, dark overall except for road systems and open areas, transmits the white light through the open areas and cultural features. On the infrared band, however, cultural features are darker tone and do not stand out. The tonal difference between the blue and infrared results in this distinct coloration for cultural features. Cultural features are also distinct when red light was used with the red band and light of a different hue with the infrared.

White light through the blue band, blue light through the green band and red light through both the red and infrared bands are the best color combination observed for differentiating vegetal types (see Plate 19). As previously stated, white light in the blue band will cause cultural features and bare areas to stand out against background tones. Natural pine stands, generally sparsely vegetated, also appear light. Blue color transmitted through the green band imparts a blue tint to light areas on this band. Although tonal differences are subtle, planted pines and deciduous trees show slight tonal differences in the visible bands. Planted pines and deciduous trees are quite distinct, however, on the infrared band. Blue light in the green band and red light in both the red and infrared bands result in a composite image with dark brown planted pine stands and reddish orange deciduous vegetation. Coloration differences for deciduous vegetation and planted pine stands are noted when different color combinations are used with the green, red, and infrared bands. Similar to the previous color combination, however, the same color was used with the red and infrared bands whereas a different color was used with the green band. In all cases white light was projected through the blue band.

By color additive viewing techniques one composite image can be formed which displays the information of the four multispectral bands. Handling and analyzing only one image instead of four, and the ease of color differentiation are distinct advantages when studying large quantities of data. Similar

results can be gained, however, by analyzing red and infrared bands of the same scene. Due to the high cost of color additive viewing apparatus and also since identical results can be gained by black and white multi-spectral analysis, color additive viewing enhancements will not be considered further.

Photographic enhancements analyzed include panatomic-X positive prints, kodalith positive prints, bas-relief prints and color additive viewing techniques. Kodalith positive prints of the visible bands are dark toned and were unsuitable for detailed analysis. Infrared kodalith prints are homogeneously coarse textured thus masking textural variations within the image. For these reasons kodalith positive prints were not studied further. Bas-relief prints enhanced linear trends but were determined to be of little importance for lithologic differentiation. Color additive viewing techniques have the advantage of forming one color composite for analysis. However, since the cost of color additive viewing is prohibitive for most analyses and since the same information can be gained from analyzing black and white multispectral bands this enhancement technique was not utilized for detailed analysis. Panatomic-X positive prints are easy and inexpensive to process, have all tonal and textural qualities of positive transparencies, are easy to manipulate, can be drawn directly upon, and can be taken into the field. Because of the above mentioned reasons panatomic-X positive prints will be used for detailed analysis.

DETAILED ANALYSIS

Tonal and textural overlays were initially constructed disregarding the topography and the lithology of the area. However, since topography is commonly controlled by underlying lithologies, topographic overlays were made from the Cottondale Quadrangle topographic map. Lithologic overlays were based on field reconnaissance and the lithologic map by Stow and Hughes (1976). Subsequent tonal and textural overlays were constructed using the topographic and lithologic overlays as control. In portions of the photos tonal and textural variations existed but differences were not distinct and contacts could not be drawn. Topographic and lithologic overlays aided in delineating subtle tonal and textural features existing on the photographs. These overlays were not used, however, for drawing contacts if no tonal or textural variations existed. Percent correlation between tonal and textural overlays, both regarding and disregarding topography and lithology, and the lithology of the area was determined. Photos were also analyzed by stereoscopic viewing. Quantitative tonal values of specific locations on the image were objectively compared with moisture and grain size analyses. Tonal values were also subjectively compared with the vegetal zonation data. After tonal values were analyzed in relation to ground truth data, a detailed photographic analysis ensued. Signatures were developed for differentiating sand, clay, alluvium, terrace deposits and indurated sandstone.

Three different scenes were analyzed and overlays were made of each multispectral band. These textural and tonal

overlays were then superimposed upon the lithologic map. Although textural and tonal features did not exactly correspond to specific lithologies, the composite area occupied by both the textural and tonal feature and the closest related lithology was determined by using a Keuffel and Esser polar planimeter. The area of overlap between the tonal and textural feature and the lithology was also determined (see Figure 8). Percent correlation was calculated by dividing total area into shared area (area of overlap) and then multiplying by 100 (% correlation = shared area/total area X 100). This method of determining percent correlation takes into account the total area between the two compared features. If total area were not considered erroneous 100% correlation values could result. 100% correlation indicates shared area equals total area and the tonal and textural feature and the corresponding lithology would be perfectly superimposed. If tonal and textural features and corresponding lithologies were of the same areal magnitude, a one half areal overlap would be 33% correlation (see figure 9 showing comparison of two features and the corresponding percent correlation.) Table 6 lists percent correlation of textural and tonal features with different lithologies. Since existing ground truth was not utilized during initial overlay preparation, the resulting correlations were poor for all bands. The infrared (clay 60% --sand 33%) and red (clay 54%--sand 29%) bands respectively, show the highest correlation percentage for delineating sand and clay lithologies. The green band (24% correlation), however, appears best for delineating recent alluvium.

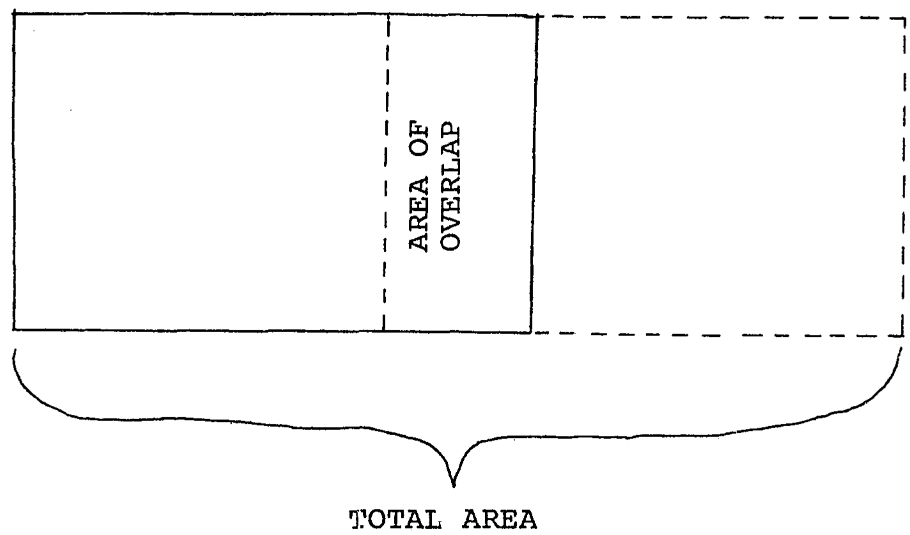

FIGURE 8

SCHEMATIC DIAGRAM SHOWING DETERMINATION OF PERCENT CORRELATION BETWEEN GROUND TRUTH AND PHOTOGRAPHIC SIGNATURE

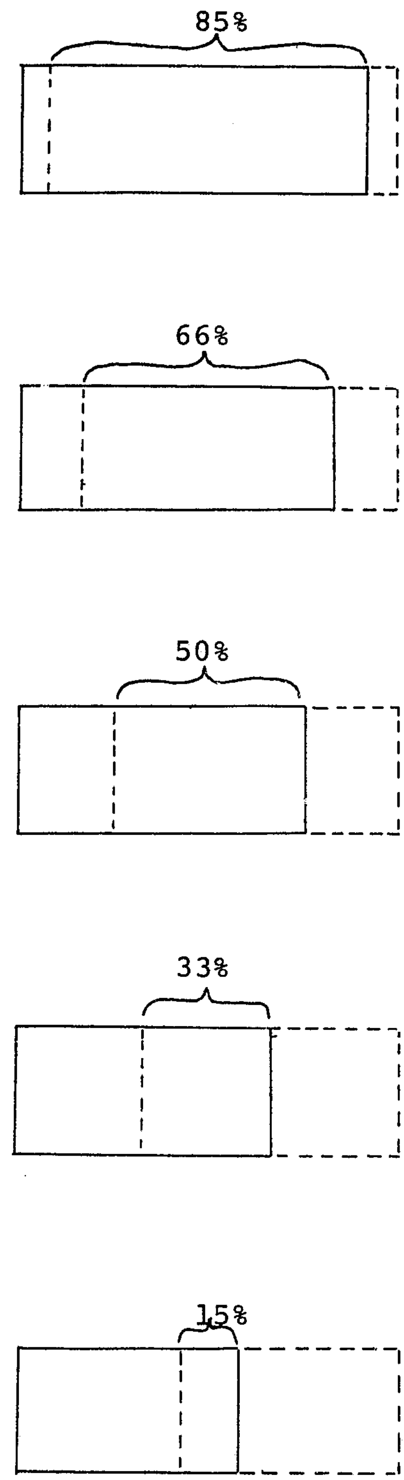

FIGURE 9

SCHEMATIC DIAGRAM SHOWING AMOUNT OF OVERLAP CORRESPONDING TO 15, 33, 50, 66 and 85% CORRELATION BETWEEN GROUND TRUTH AND PHOTOGRAPHIC SIGNATURE

TABLE 6

PERCENT CORRELATION BETWEEN TONE AND LITHOLOGIES FOR EACH OF THE FOUR MULTISPECTRAL BANDS

Disregarding Topography And Lithology

	Blue	Green	Red	Infrared
Sand	27%	19%	29%	33%
Clay	52%	41%	54%	60%
Alluvium	0.0%	24%	21%	0.0%

Regarding Topography And Lithology

	Blue	Green	Red	Infrared
Sand	35%	32%	54%	62%
Clay	58%	47%	64%	69%
Alluvium	72%	81%	70%	76%

Since topographic differences are commonly controlled by lithologic type, tonal and textural overlays constructed with regard to topography should have a higher percent correlation than the previously constructed overlays. Both topographic and lithologic overlays were constructed of the study area by using a thermofax copier and were used as control for tonal and textural overlay development. When these overlays were compared with previous overlays percent correlation between tonal and textural features and lithologies increased for all four multi-spectral bands.

The area of study, delineated on the topographic map, was photographed using panatomic-X film. Light passed through the negatives, which were placed in an enlarger, formed an image of the topographic map. The multispectral panatomic prints were placed under the light source and the topographic image was superimposed on the print. The enlarger was adjusted until the image and the multispectral print were the same scale (exactly superimposed). The multispectral print was removed from the enlarger and a print of the topographic negative was made.
A xerox copy of the topographic map photograph was run through a thermofax copier forming a black line topographic transparency. Thermofax copiers can only make transparencies from xerox copies, therefore, a grid was photographed, xeroxed, and run through the thermofax copier to check for distortion. Distortion due to xeroxing was slight but did occur around photo margins (see plate 20). The black line topographic transparency was then used as an overlay as an aid in drawing

contacts between different tonal and textural features on multispectral prints (Plate 21). A lithologic map of the study area was also photographed, printed, and processed through the thermofax copier. The black line lithologic transparency was used with the topographic transparency for constructing tonal and textural overlays (Plate 22). Percent correlation was increased for all multispectral bands relative to overlays disregarding topography and lithology. For differentiating clay (69%) and sand (62%) lithologies the infrared band has the highest percent correlation. The largest percent correlation increase (33%--62%) is for sand differentiation using the infrared band. Distinct differences are evident on the infrared band but accurate contacts can not be drawn. Topographic and lithologic overlays result in more accurate contact delineation between tonal and textural features. The visible bands do not show as distinct tonal and textural differences as do the infrared band, therefore topographic and lithologic aids are not as useful with visible bands. Alluvial deposits are readily delineated by tonal variation on all multispectral bands.

Since topographic position was used as an aid in tonal and textural overlay preparation, each multispectral band was analyzed by stereoscopic viewing. Stereoscopic viewing visualizes the image in three dimensions, and eliminates the need for topographic overlays. Topographic overlays can possibly be mis-interpreted and may be also slightly inaccurate due to xerox distortion in their preparation. Stereoscopic viewing,

instead of topographic overlays, is recommended for analyzing multispectral photographs.

Quantitative tonal values, for each multispectral band, were determined for ten specific locations within the study area. Locations chosen for tonal value determination were the same as those for moisture and grain size ground truth data. (see figure 3). Quantitative tonal values were graphically compared with both the moisture and grain size values and were plotted, as separate graphs, along the abcissa. A straight line was drawn through the plotted points using "least squares fit". Pearson or product-moment correlation coefficients, which measure the degree to which a straight line relating two values can summarize the trend in a scatter plot, were determined.

A Jarrell-Ash 21-000 microphotometer was used to calculate quantitative tonal values from multispectral positive transparencies. Since panatomic-X positive prints are spectrally equivalent to positive transparencies, these quantitative tonal values can be applied to positive prints. The multispectral positive transparencies were mounted on the viewing screen with a light source below the microphotometer. A silt, .05mm long and .045mm wide, was mechanically scanned across the transparency at a rate of 25mm/minutes. Slit dimensions transposed to ground dimensions would be 1.2 meters long by 1.0 meter wide and ground surface scanning rate would be 10 meters/second. Light transmitted through the transparency and subsequently through the slit was recorded on a graph. The sensitivity of the microphotometer can be adjusted so the graph reads 0 when

all light is shut out (black areas of the transparency) and reads 100 when the slit passes a clear area on the transparency. The graph thus is adjusted to read directly in percent light transmission. The graph was more uniform (lacking numerous minor fluctuations) and general tonal trends were easier to read when the sensitivity setting was low. With low sensitivity settings, however, clear areas did not read 100% on the graph. This problem was alleviated by dividing the reading of the clear area into 100%, thus deriving a conversion factor. The percent light transmission of any point was then determined by multiplying the graph reading for that particular point times the conversion factor. Each time the sensitivity was changed a new conversion factor was determined. Four scans were made across each positive transparency band. Each of the ten individual sampling locations was passed over by the four scans. For each sampling location light transmission was read directly off the graph and was multiplied by the proper conversion factor thereby determining percent. Table 7 lists percent light transmission for the four multispectral bands for each sampling locality.

Percent light transmission is abnormally low on all bands for locations 8, 9, and 10. This decrease in light transmission was due to these sampling locations proximity to the darkened photograph edge. These locations were disregarded and were not included in quantitative comparison with ground truth data. Sampling location #3 was also eliminated from comparison. Subsequent field investigations indicated this area was possibly pasture and not naturally vegetated.

TABLE 7

PERCENT LIGHT TRANSMISSION OF SAMPLING LOCATIONS FOR EACH MULTI-SPECTRAL BAND

BAND	LOCATIONS	PERCENT LIGHT TRANSMISSION
Blue (1)	1	50.0
	2	95.0
	3	72.0
	4	68.0
	5	60.0
	6	52.0
	7	55.0
	8	29.0
	9	34.0
	10	46.0
Green (2)	1	21.0
	2	80.0
	3	30.0
	4	40.0
	5	25.0
	6	22.0
	7	21.0
	8	4.0
	9	8.0
	10	8.0
Red (3)	1	28.0
	2	53.0
	3	51.0
	4	53.0
	5	37.0
	6	32.0
	7	41.0
	8	4.0
	9	6.0
	10	18.0
Infrared (4)	1	70.0
	2	50.0
	3	37.5
	4	50.0
	5	65.0
	6	72.5
	7	42.5
	8	32.5
	9	20.0
	10	50.0

Ground truth data were quantitatively compared with percent light transmission for sampling locations 1, 2, 4, 5, 6, and 7. The mean grain size was calculated for each of the five samples collected at each sampling location. The average mean grain size was determined for each location and was plotted versus light transmission (See figures 10, 11, 12, and 13). A straight line was statistically drawn using "least squares fit." The formula for determining slope of the line was M(slope of line) $= N\ (\Sigma Xi\ Yi) - (\Sigma Xi)\ (\Sigma Yi)/N\ (\Sigma Xi^2) - (\ Xi)^2$. The value of the ordinate when the absicca is zero was determined by the formula $B = (\Sigma Yi)\ (\Sigma Xi^2) - (\Sigma Xi\ Yi)\ (\Sigma Xi)/N\ (\Sigma Xi^2) - (\Sigma Xi)^2$. See Young (1962) for a detailed discussion concerning "least squares fit".

The correlation coefficients, when comparing percent light transmission versus average mean grain size, for the blue, green, red, and infrared bands are -.66, -.61, -.995, and .96, respectively. Note that higher correlation values were calculated for the red and infrared bands. This quantitative comparison substantiates previous subjective observations which were noted when constructing tonal and textural overlays. Although the overlays were drawn by subjective analysis the percent correlation between overlays and lithologies is greater for the red and infrared bands.

Percent light transmission for the previously mentioned locations was also compared with the two different sets of moisture data. The average moisture percent, for each sampling location, was plotted versus percent light transmission and formed a scatter diagram (See figures 14, 15, 16 and 17).

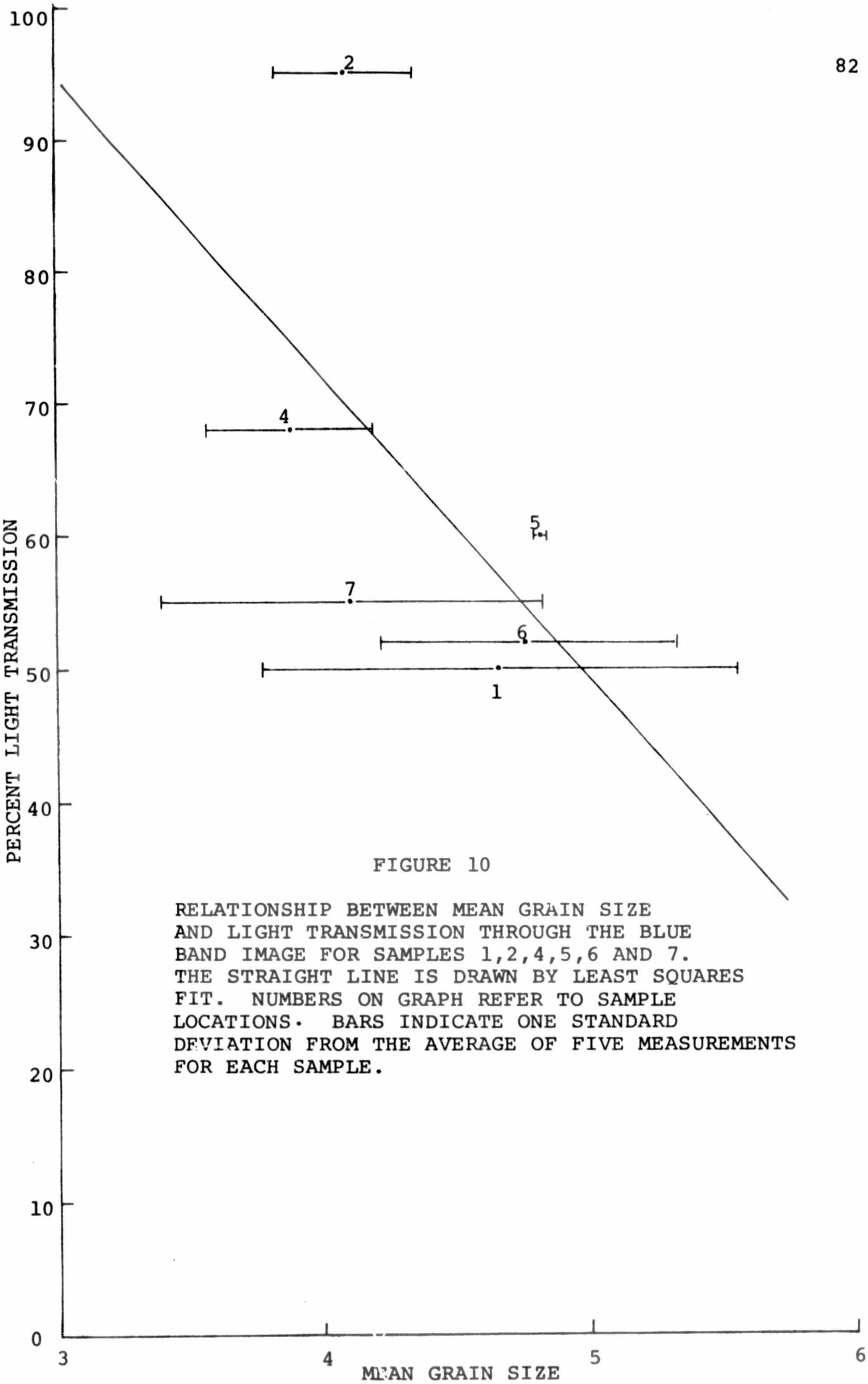

FIGURE 10

RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND LIGHT TRANSMISSION THROUGH THE BLUE BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE STRAIGHT LINE IS DRAWN BY LEAST SQUARES FIT. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. BARS INDICATE ONE STANDARD DEVIATION FROM THE AVERAGE OF FIVE MEASUREMENTS FOR EACH SAMPLE.

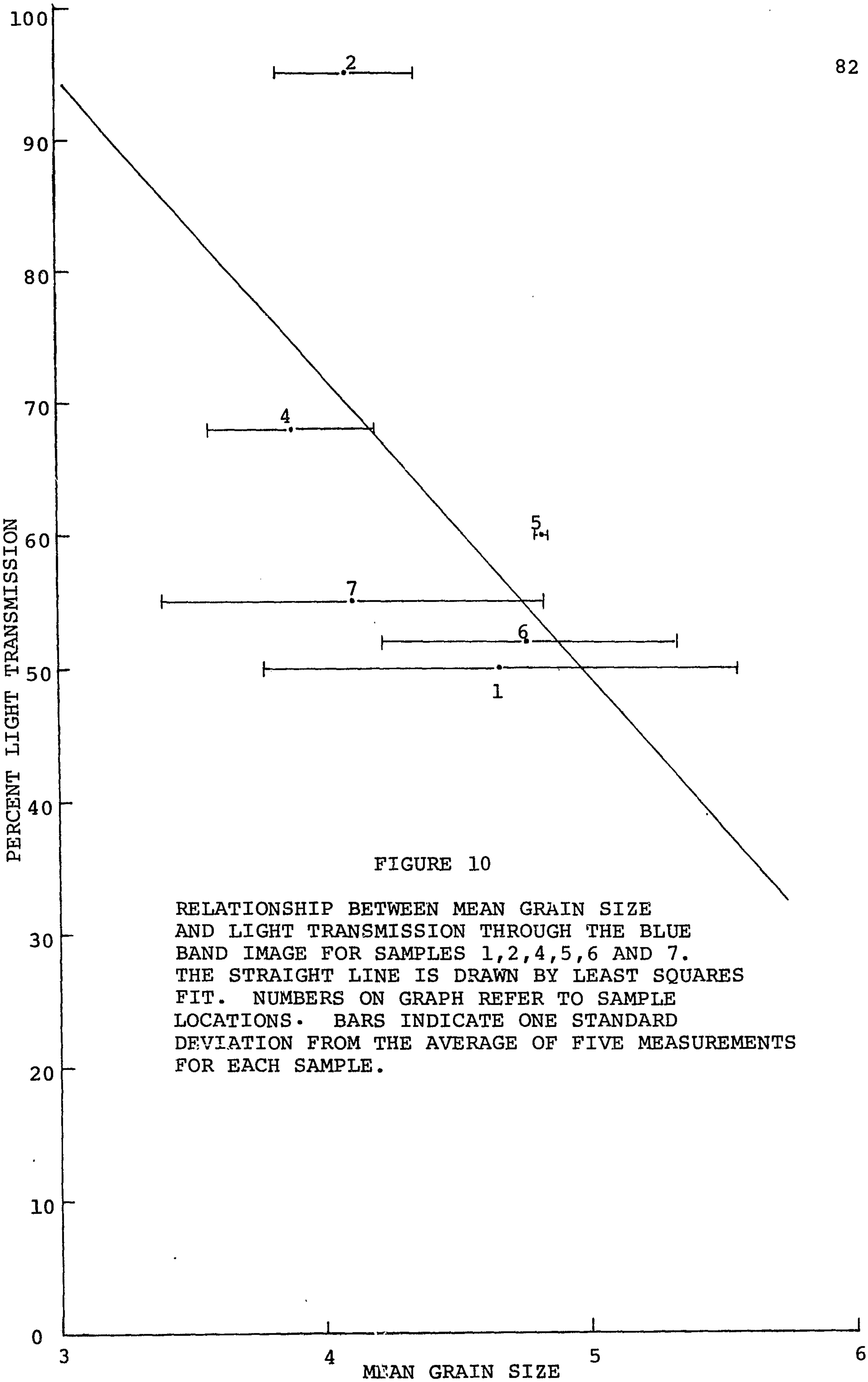

FIGURE 10

RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND LIGHT TRANSMISSION THROUGH THE BLUE BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE STRAIGHT LINE IS DRAWN BY LEAST SQUARES FIT. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. BARS INDICATE ONE STANDARD DEVIATION FROM THE AVERAGE OF FIVE MEASUREMENTS FOR EACH SAMPLE.

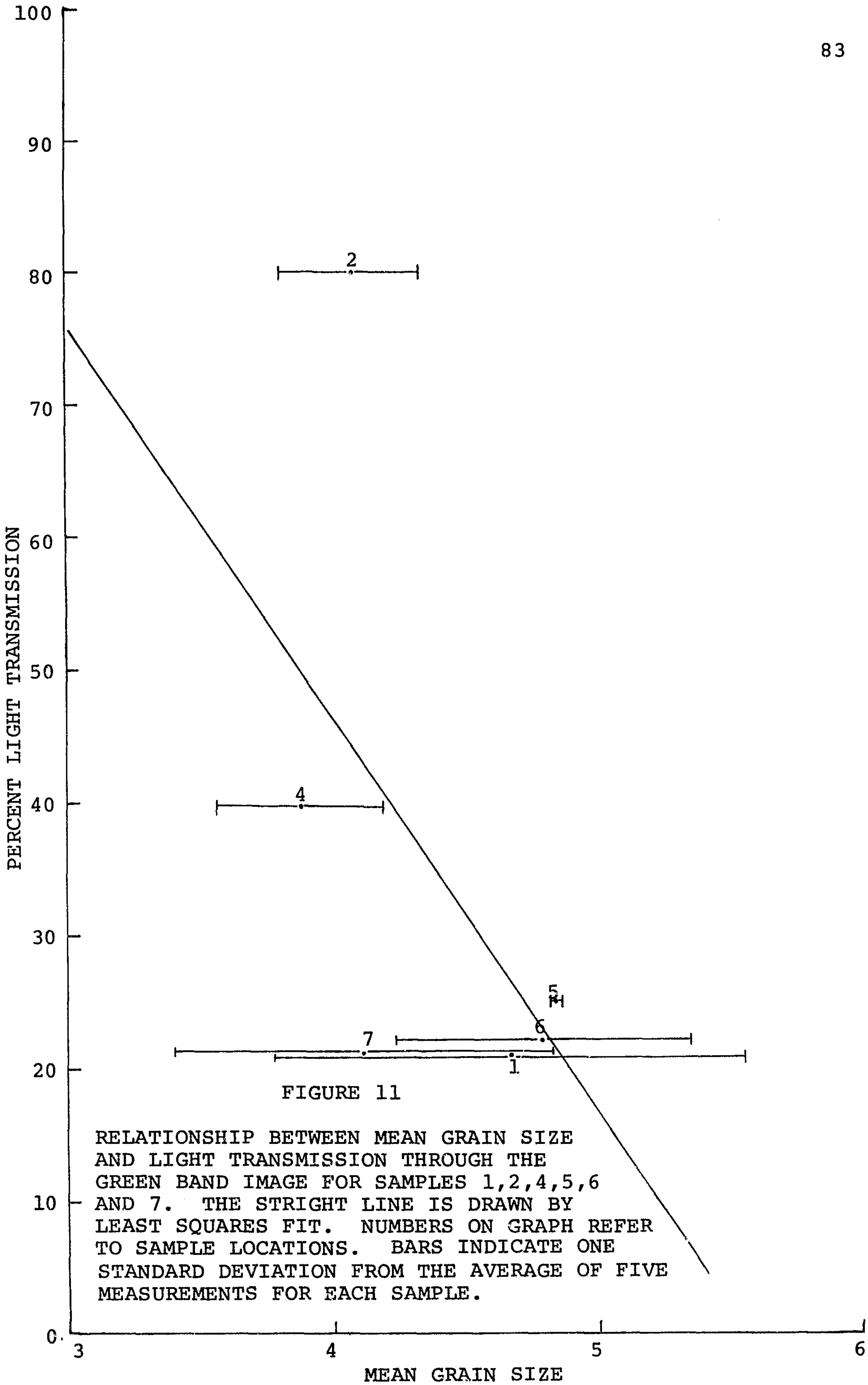

FIGURE 11

RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND LIGHT TRANSMISSION THROUGH THE GREEN BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE STRIGHT LINE IS DRAWN BY LEAST SQUARES FIT. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. BARS INDICATE ONE STANDARD DEVIATION FROM THE AVERAGE OF FIVE MEASUREMENTS FOR EACH SAMPLE.

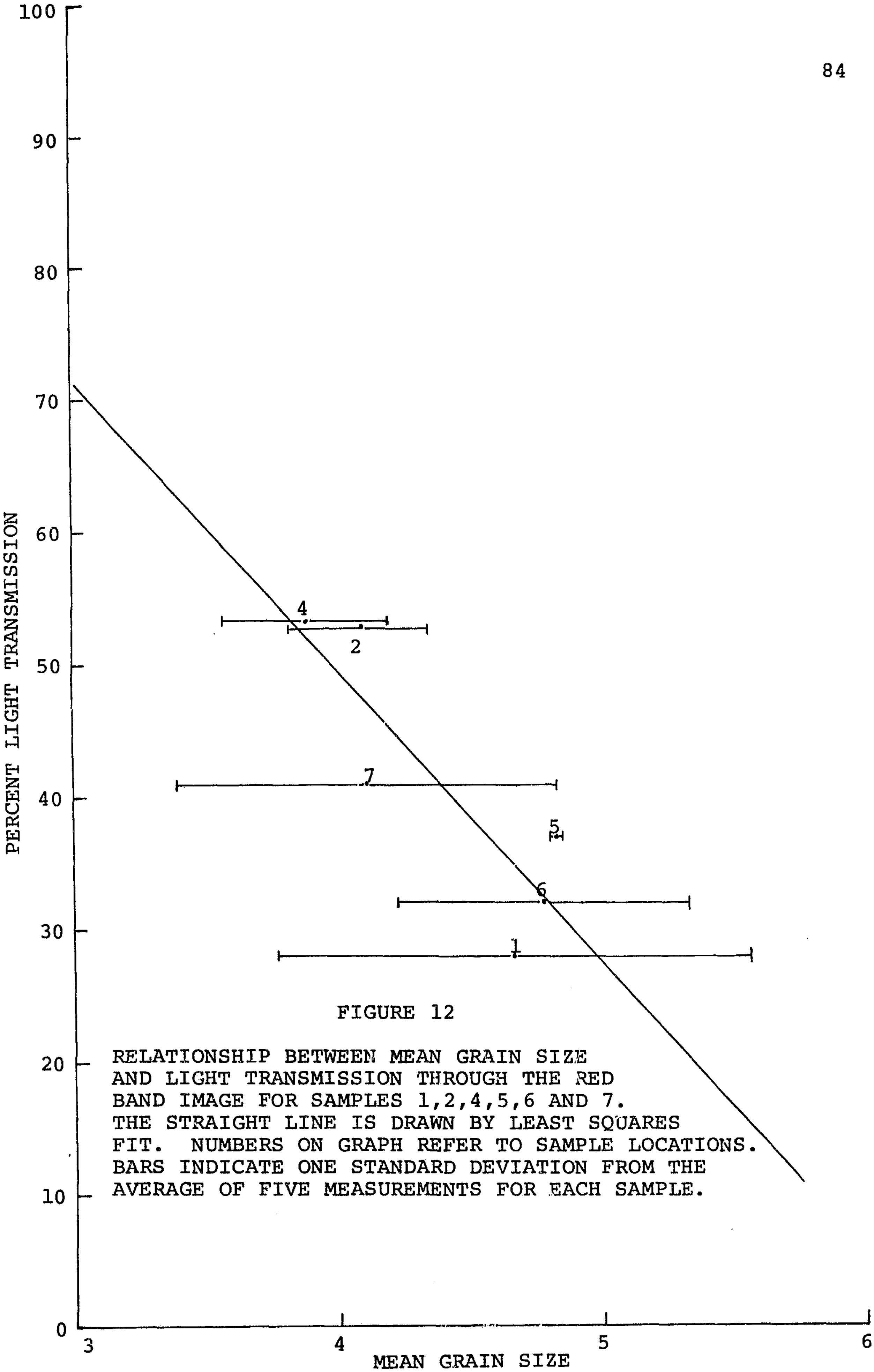

FIGURE 12

RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND LIGHT TRANSMISSION THROUGH THE RED BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE STRAIGHT LINE IS DRAWN BY LEAST SQUARES FIT. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. BARS INDICATE ONE STANDARD DEVIATION FROM THE AVERAGE OF FIVE MEASUREMENTS FOR EACH SAMPLE.

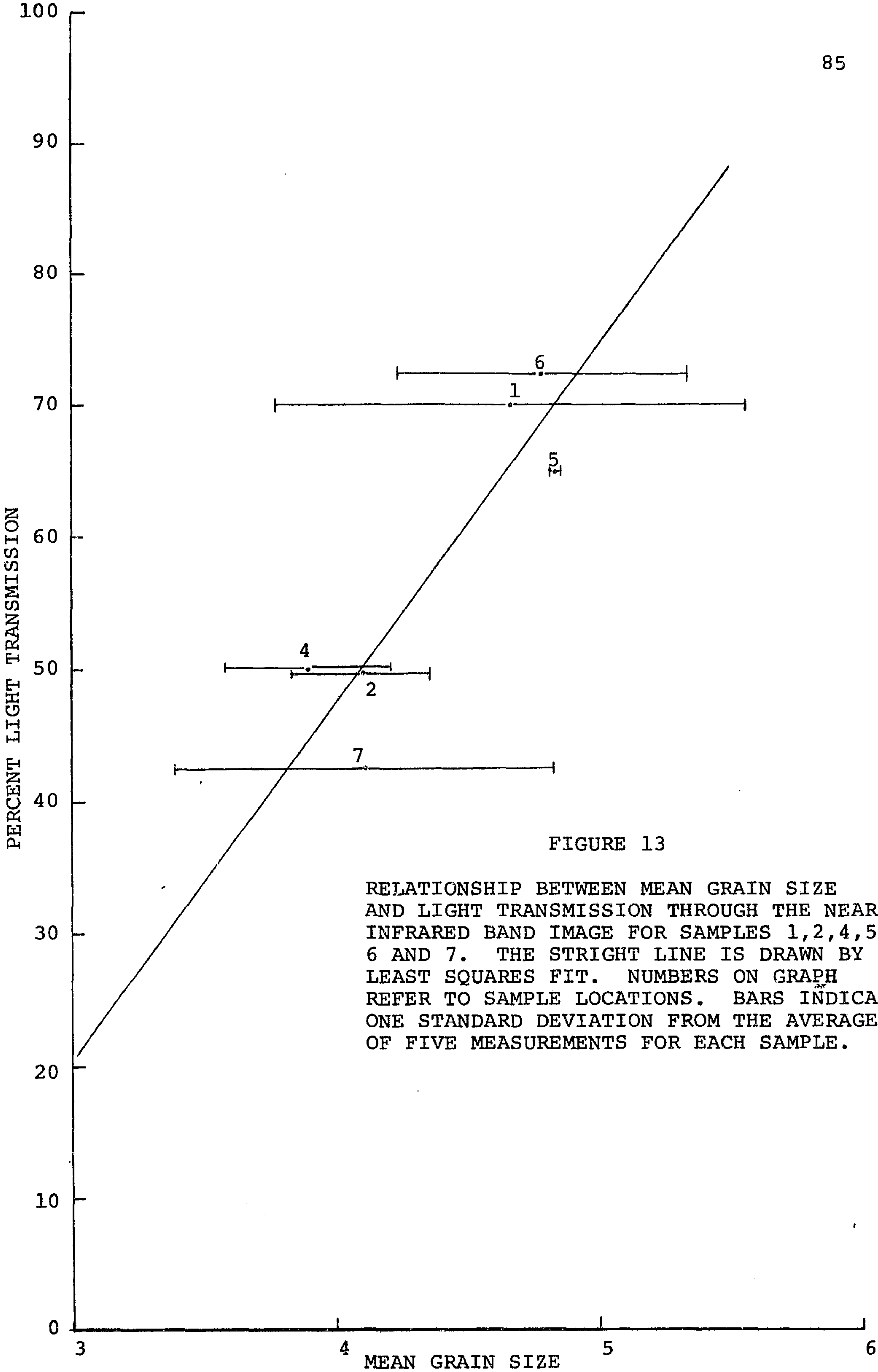

FIGURE 13

RELATIONSHIP BETWEEN MEAN GRAIN SIZE AND LIGHT TRANSMISSION THROUGH THE NEAR INFRARED BAND IMAGE FOR SAMPLES 1,2,4,5, 6 AND 7. THE STRIGHT LINE IS DRAWN BY LEAST SQUARES FIT. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. BARS INDICATE ONE STANDARD DEVIATION FROM THE AVERAGE OF FIVE MEASUREMENTS FOR EACH SAMPLE.

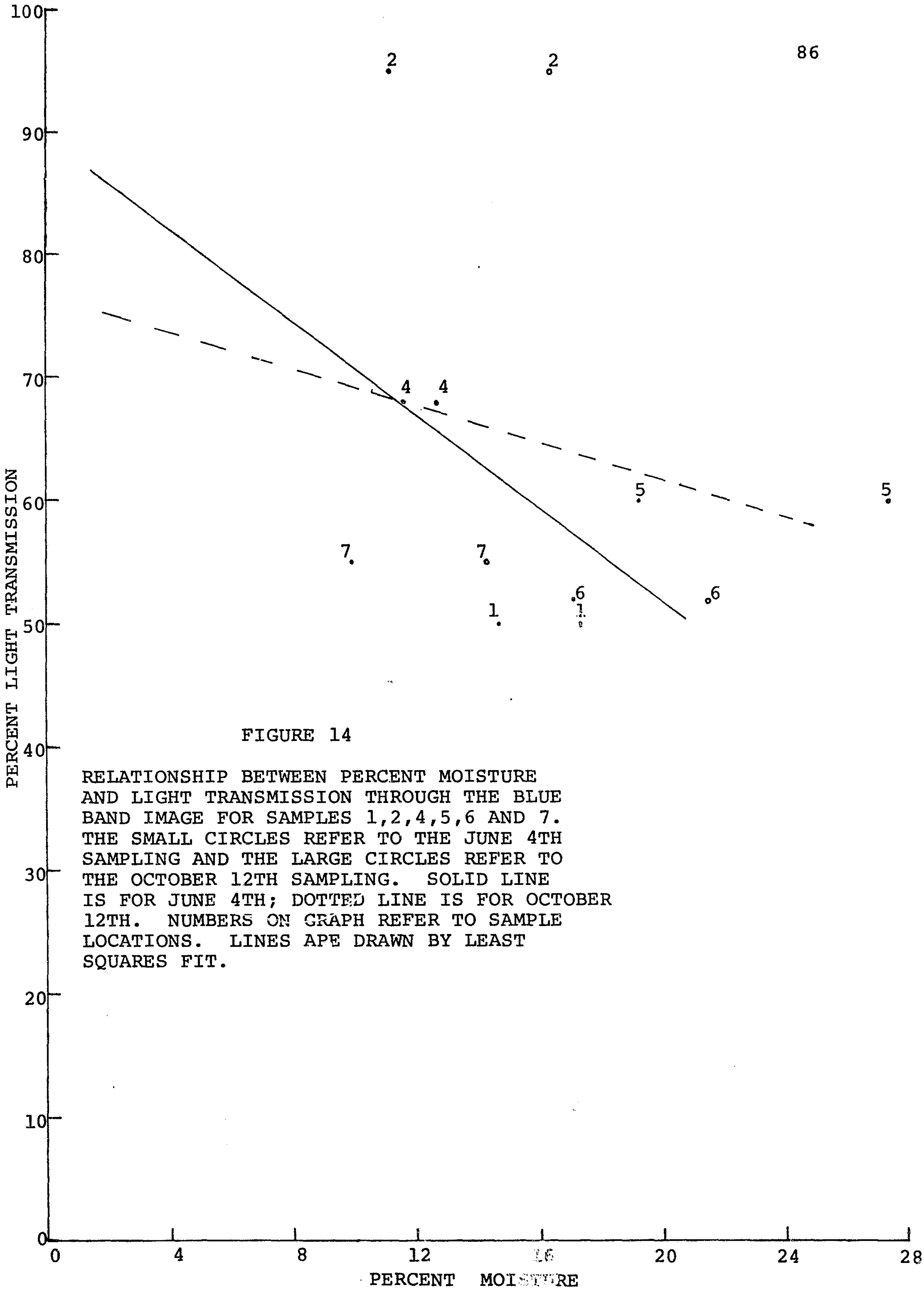

FIGURE 14

RELATIONSHIP BETWEEN PERCENT MOISTURE AND LIGHT TRANSMISSION THROUGH THE BLUE BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE SMALL CIRCLES REFER TO THE JUNE 4TH SAMPLING AND THE LARGE CIRCLES REFER TO THE OCTOBER 12TH SAMPLING. SOLID LINE IS FOR JUNE 4TH; DOTTED LINE IS FOR OCTOBER 12TH. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. LINES ARE DRAWN BY LEAST SQUARES FIT.

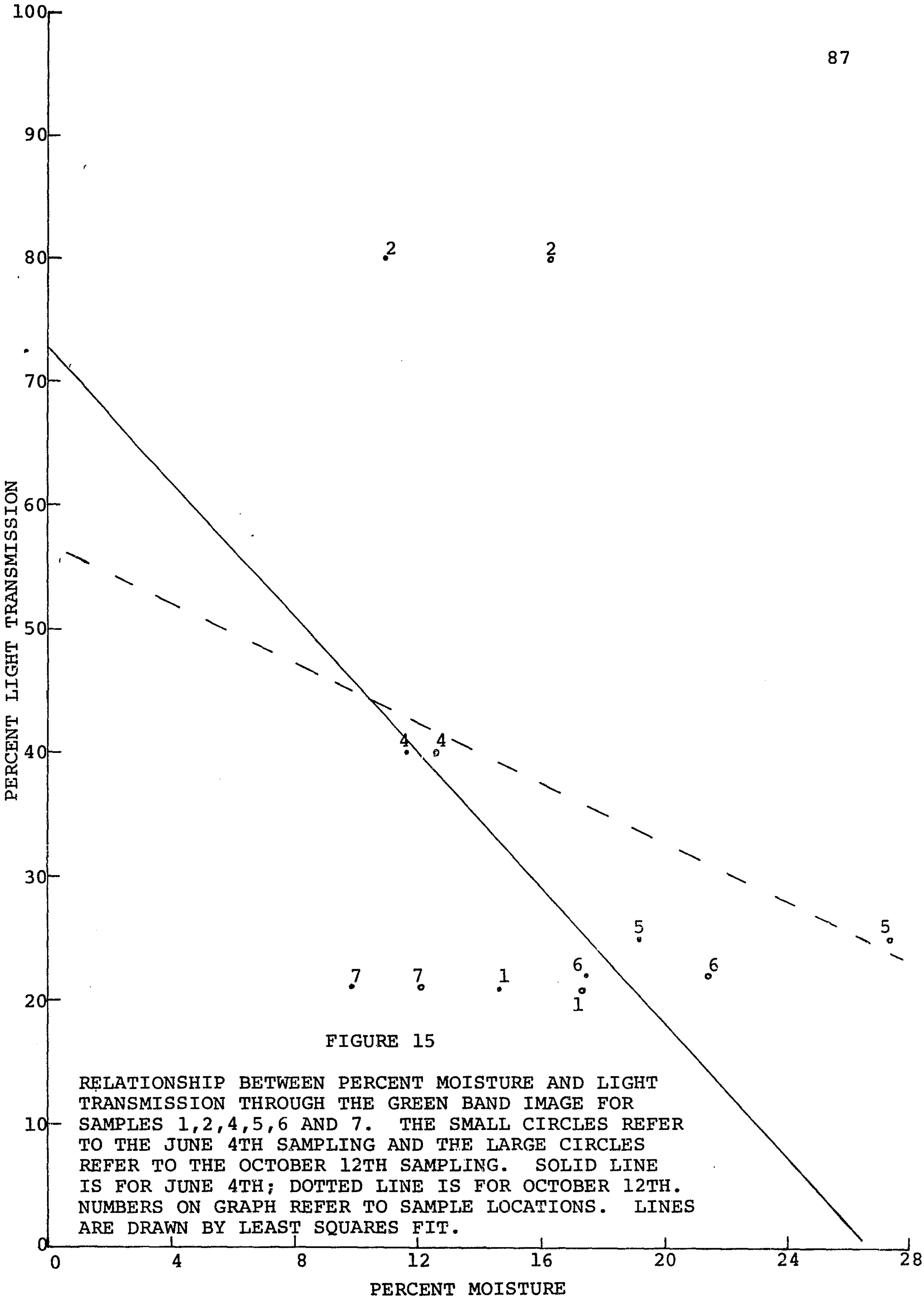

FIGURE 15

RELATIONSHIP BETWEEN PERCENT MOISTURE AND LIGHT TRANSMISSION THROUGH THE GREEN BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE SMALL CIRCLES REFER TO THE JUNE 4TH SAMPLING AND THE LARGE CIRCLES REFER TO THE OCTOBER 12TH SAMPLING. SOLID LINE IS FOR JUNE 4TH; DOTTED LINE IS FOR OCTOBER 12TH. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. LINES ARE DRAWN BY LEAST SQUARES FIT.

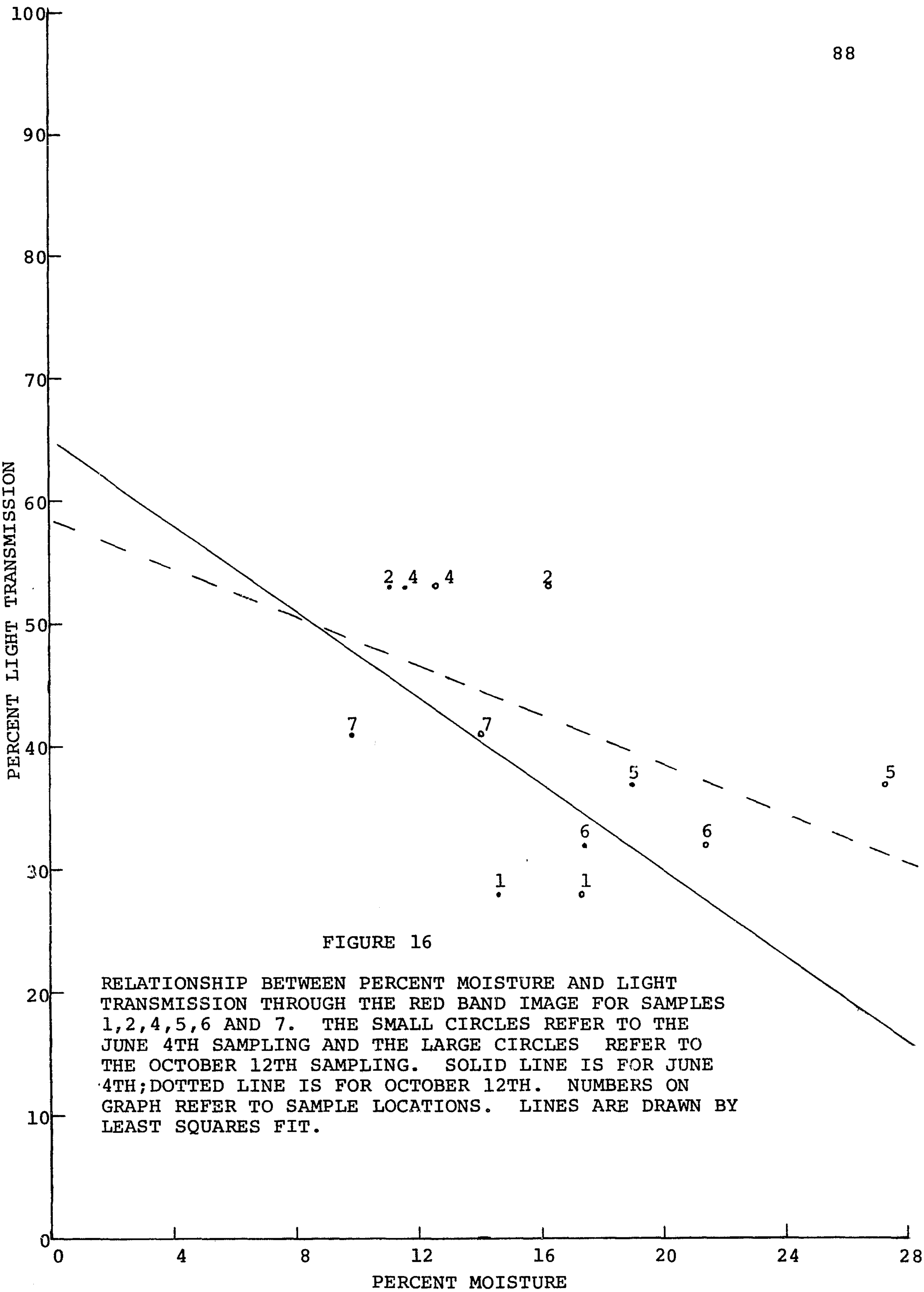

FIGURE 16

RELATIONSHIP BETWEEN PERCENT MOISTURE AND LIGHT TRANSMISSION THROUGH THE RED BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE SMALL CIRCLES REFER TO THE JUNE 4TH SAMPLING AND THE LARGE CIRCLES REFER TO THE OCTOBER 12TH SAMPLING. SOLID LINE IS FOR JUNE 4TH; DOTTED LINE IS FOR OCTOBER 12TH. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. LINES ARE DRAWN BY LEAST SQUARES FIT.

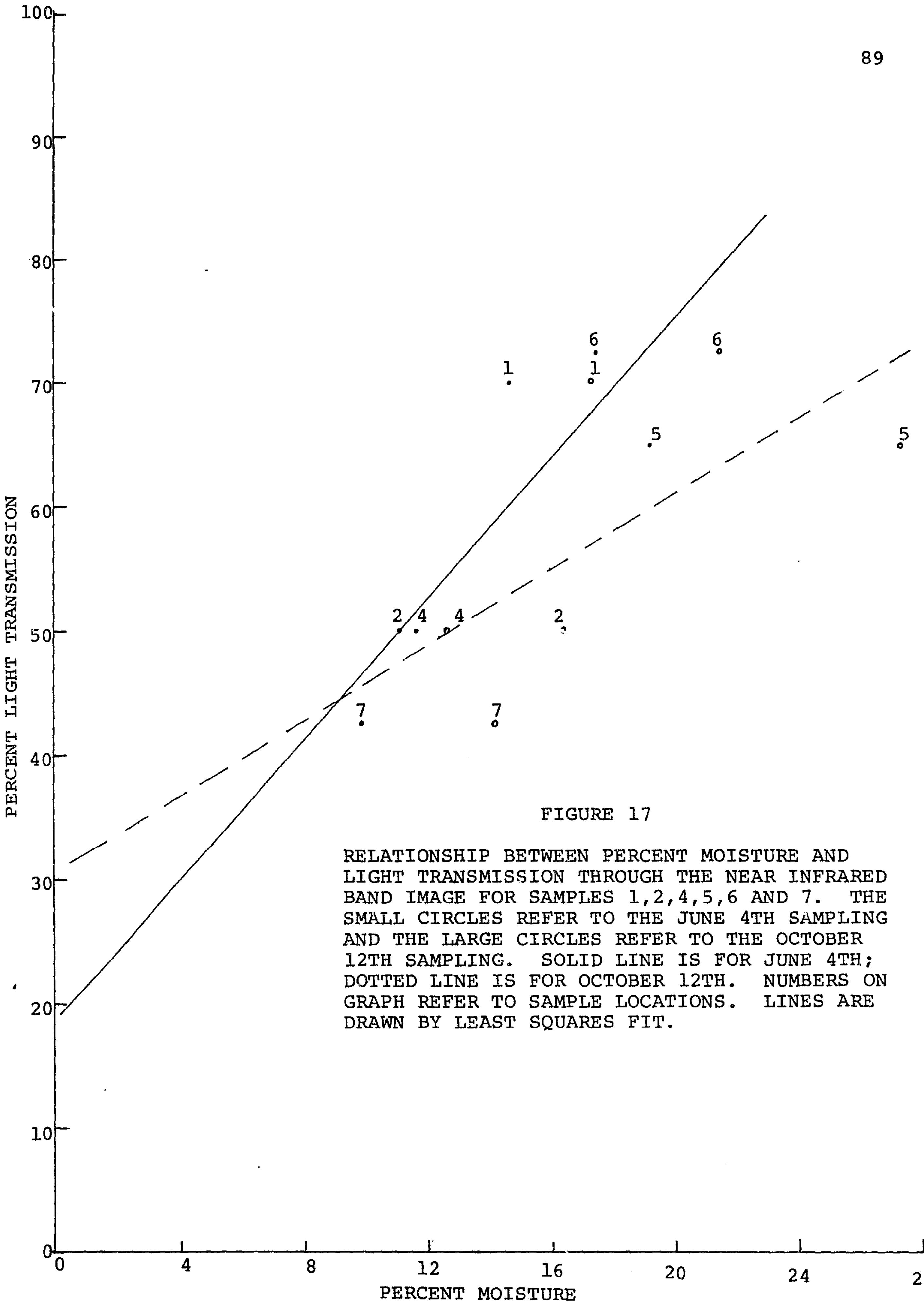

FIGURE 17

RELATIONSHIP BETWEEN PERCENT MOISTURE AND LIGHT TRANSMISSION THROUGH THE NEAR INFRARED BAND IMAGE FOR SAMPLES 1,2,4,5,6 AND 7. THE SMALL CIRCLES REFER TO THE JUNE 4TH SAMPLING AND THE LARGE CIRCLES REFER TO THE OCTOBER 12TH SAMPLING. SOLID LINE IS FOR JUNE 4TH; DOTTED LINE IS FOR OCTOBER 12TH. NUMBERS ON GRAPH REFER TO SAMPLE LOCATIONS. LINES ARE DRAWN BY LEAST SQUARES FIT.

Correlation coefficients are listed in table 8. The red and infrared bands show higher correlation coefficients, for both sets of moisture data, than do the blue and green bands. Overall, moisture data collected on October 12th showed lower correlation coefficients than did data collected on June 4th. Precipitation the morning of October 12th was postulated as the cause of these poor correlations since ubiquitous moisture coverage would mask moisture differences due to underlying lithologies. Moisture variance should be greater during dry weather conditions.

According to Spence and others (1968), "a correlational study rarely indicates which variable influences which, or even whether either variable is influencing the other directly." Although good correlation exists between percent light transmission and grain size for the infrared and red bands, the two variables are not directly related. As previously discussed tonal and textural qualities of photos are directly related to vegetative type, topographic configuration, and weathering and drainage characteristics. These factors would be, however, in part controlled by lithologic type. The importance of the correlation coefficient is in predicting one variable when a particular value of the other is known. Since percent light transmission and grain size have a high correlation coefficient one variable may be estimated from the other and tonal and textural signatures on multispectral imagery appear to be valuable for predicting lithologic types. Moisture percent and percent light transmission also have a high

TABLE 8

CORRELATION COEFFICIENTS FOR EACH MULTISPECTRAL BAND WHEN TWO DIFFERENT SETS OF MOISTURE DATA WERE PLOTTED VERSUS PERCENT LIGHT TRANSMISSION

MULTISPECTRAL BAND	CORRELATION COEFFICIENT	
	June 4, 1974	Oct. 12, 1974
Blue	-0.40	-0.23
Green	-0.43	-0.28
Red	-0.62	-0.50
Infrared	0.86	0.66

correlation coefficient. Moisture percent, like grain size, can be indirectly related to percent light transmission.

Since vegetative types vary depending on slope exposure, quantitative comparisons between vegetative types and percent light transmission of imagery was not attempted. However, subjective comparisons were made.

Subjective comparisons of quantitative data substantiate previous subjective tonal differences noted on multispectral imagery. Generally, clay lithologies support lush deciduous vegetation and appear dark toned on visible bands (Avery, 1968, and Wanless, 1965). Deciduous vegetation, highly reflective in the infrared, appears light toned (Pestrong, 1969). Clay hills show no tonal differences depending on slope orientation.

Sand lithologies generally support conifers and are less densely vegetated than clay lithologies. On visible bands sand lithologies generally appear light toned (Avery, 1968) while they image dark toned on the infrared band. Sand hills, however, support different vegetal types depending on slope orientation. Closer analysis of sand hills, with a stereoscope, also showed tonal differences depending on slope exposure. South facing sandy slopes imaged lighter, in the visible range, than did the contiguous north facing sandy slope. This tonal difference, however, is difficult to see on the visible bands since low topographic reflectance (dark tone) tends to cancel high reflectance due to lithology. However, south facing sandy slopes appeared dark on infrared imagery while north facing slopes were lighter toned.

Since south facing slopes are generally more gently inclined than north facing slopes, reflectance to the sensor due to this topographic variation would be greater for south facing slopes. Greater reflectance would cause this portion of the photograph (south slope) to be lighter. This tonal difference is opposite the tonal variation that is actually seen on the infrared band. Since slope angle differences are slight the resulting tonal differences are also slight. Dark south slopes due to vegetative types would override the slightly higher reflectance due to slope angle.

Photographic tonal variance, due to slope exposure, of hills should be an important indicator for identifying sand lithologies. Clay hills, however, should be lighter and should exhibit a more uniform tone.

Recognizable signatures on the infrared band were developed for sand, clay, alluvium, terrace deposits, and indurated sandstone. Analysis of the infrared band should be conducted in conjunction with the red band. The red and infrared band combination can be used to delineate natural and planted pines. The red band can also be used to delineate cleared land and manmade cultural features.

Mintzer (1968) recognized the need to integrate all causal reflectances from photograph surface and to ultimately formulate a reliable signature. Reflectances are primarily caused by vegetative cover, topography, and erosion and drainage characteristics. These factors result in specific tonal and textural characteristics which in turn can be related to specific

underlying lithologies. Tonal and textural signatures for lithologic types are as follows:

Infrared Band

Sand (Plate 23) Sand hills are generally dark toned. Closer analysis with a stereoscope indicated tonal separation due to slope exposure. North facing slopes imaged lighter than did south facing slopes. The tonal differences are gradational and might be overlooked if careful analysis with a stereoscope is not conducted. Sandy slopes also image dark but are homogeneously textured. This homogeneous photograph texture is probably due to the regular terrain which lacks a fine textural drainage system. Gulleys or valleys which do form are generally V-shaped and have steep sides.

Clay (Plate 23) Clay hills vary from a homogeneous light tone to a darker mottled appearance. Mottled clay hills are topographically higher than are light toned clay hills. The mottled appearance could be controlled by high reflectance of vegetative types and low reflectance due to topographic position and slope angle. Moisture variance due to high topographic position could also cause spectral responses (tonal differences) to vary. Topographically high clay hills could be confused with sand hills. Clay hills, however, are coarse textured, mottled, and do not exhibit tonal variance due to north-south slope exposure. The coarse texture could be controlled by a more extensively developed drainage system which would have a variety of slope angles and would result in a coarse texture photograph appearance. Valleys or gulleys would have gently sloping sides with a broad flat base.

C 2

Lower clay hills, coarse textured and light toned, are spectrally similar to alluvial deposits but are easily differentiated by their topographic position.

Clay slopes and lowlands are finer textured due to the level terrain, and are also light toned.

Alluvium (Plate 24) Areas of alluvial deposition generally appear light toned, coarse textured and mottled in appearance. The predominate light tone is due to the abundance of lush vegetation that border streams or creeks. This light area would correspond to the sandy areas which are generally dark toned on the infrared band. Other light signatures on the image might be confused with alluvial deposits if it were not for the topographic position and characteristic coarse grained and mottled appearance. Dark areas, usually combined with the light areas, are probably due to absorption by water in the creek and along the back swamps. This combination of light and dark result in the mottled appearance. A continuous dark line is not shown by water absorption along the stream course. This is probably due to vegetation, causing a high reflectance, in places hanging over the stream. A continuous dark line would be characteristic of larger streams or rivers. As distance from the stream increases, the photograph becomes more medium textured and slightly darker (although still light overall). This is probably indicative of clay deposits and indicates the fine grained back swamp deposits.

Terrace Deposits Terrace deposits vary depending on the underlying lithology. Regardless of the tonal response, terrace

deposits should appear homogeneously textured. This textural characteristic would be controlled by the flat terrace surface reflecting light evenly to the sensor. Terrace deposits would best be delineated by the broad flat areal distribution and the proximity to adjacent streams.

Indurated Sandstone (Plate 25) Sandstone is coarse textured and light and dark mottled in appearance. Predominantly dark, sandstone hills resemble unconsolidated sand hills. Sand hills, however, lack the mottled appearance and the coarse texture of sandstone hills. Sandstone hills can be differentiated from mottled clay hills by the varied topography and steep valley walls. The dissected topography of the sandstone hills cause the coarse mottled texture.

Characteristic signatures can be used to delineate broad lithologic types in a vegetated region. Due to the numerous variables that must be considered during analysis, intermediate lithologies cannot be readily identified. Slight man-made disturbances of the reflectance surface could cause misinterpretations.

CONCLUSIONS

Analyses of multispectral photographs taken in vegetative regions indicate that rock types can be differentiated. Electromagnetic radiation is reflected to the remote sensor primarily from vegetative surfaces. Underlying lithologies are frequently the dominant factor controlling vegetative distribution. Optimum time of flight for differentiating vegetation is during late spring.

Multispectral photographs were enhanced by using the color additive viewer and by photographing and printing as kodalith and panotomic-X positive prints and as bas-relief positive prints. Panotomic-X prints were economical, were easy to use, and showed as much, if not more, detail than other type enhancements.

Studies were conducted to show the correlation between tonal values of the multispectral images and ground truth data such as lithology and moisture percent. High correlation was noted for both the red and infrared bands. Lithologic map construction when using the red and infrared bands increased significantly when maps were drawn in conjunction with existing ground truth data. Photographs should always be viewed stereoscopically prior to constructing lithologic maps. Field work must also be an essential part of map construction.

Characteristic signatures were developed to delineate broad lithologic types. Multispectral analysis for lithologic

determinations will prove beneficial if limited time is a factor and if areas to be mapped have limited accessibility.

APPENDIX I

MOISTURE PERCENT FOR 50 DIFFERENT SAMPLES COLLECTED ON JUNE 3, 1974 AND ON OCTOBER 12, 1974

LOCATION	SAMPLE #	MOISTURE PERCENT June 4, 1974	MOISTURE PERCENT Oct. 12, 1974
1	1	14.54	13.62
	2	21.56	27.46
	3	11.18	12.90
	4	13.25	20.38
	5	12.68	12.25
2	1	10.27	14.32
	2	12.25	13.06
	3	11.27	17.40
	4	12.33	20.06
	5	9.61	16.89
3	1	15.48	16.00
	2	8.45	11.87
	3	12.15	14.13
	4	10.47	14.68
	5	14.45	16.03
4	1	11.89	13.01
	2	12.99	14.58
	3	9.97	11.52
	4	11.85	12.17
	5	11.44	11.68
5	1	14.19	31.10
	2	15.84	18.53
	3	23.34	36.04
	4	25.52	27.12
	5	17.13	16.69
6	1	25.59	23.20
	2	15.52	22.53
	3	28.66	23.48
	4	7.12	17.61
	5	10.27	20.33
7	1	6.48	15.87
	2	11.18	12.18
	3	13.85	16.75
	4	8.72	12.42
	5	9.18	13.41

APPENDIX I, CONT.

LOCATION	SAMPLE #	MOISTURE PERCENT June 4, 1974	MOISTURE PERCENT Oct. 12, 1974
8	1	13.25	16.32
	2	14.01	15.60
	3	14.09	15.00
	4	10.35	16.30
	5	12.03	16.60
9	1	12.24	20.56
	2	12.78	18.65
	3	10.13	13.40
	4	16.17	16.21
	5	10.64	17.21
10	1	8.90	15.10
	2	16.23	16.59
	3	12.17	18.46
	4	10.45	16.98
	5	9.98	13.73

APPENDIX 2

Numbers of trees by species and site

Species:	Site: 1	2	3	4	5	6	7	8
Black Cherry								22
Black Gum	56	3		1	3			6
Black Jack Oak		36	33	15	9	62	2	
Black Oak	1		5	11	46	5	3	6
Black Willow	1							
Chestnut Oak				20				
Dogwood			10	7	6	3		1
Hickories	2		6	10	25	4		9
Hop Hornbeam					1			
Loblolly Pine	9	35	6	4	3	27	41	8
Longleaf Pine		47	2					
Post Oak	1		54	17	20	42	2	7
Red Maple	11			2				
Scarlet Oak			1					1
Scrub Pine - Shortleaf Pine		16	14	49	14	52	19	12
Sourwood				19	22	10	1	2
Southern Red Oak	2	1	3	13	24	24	8	16
Sweet Bay	1							
Sweetgum	19	2	9	17	16	11	2	3
Umbrella Tree				1	1			
Water Oak	3				1		1	1
White Oak			1	14	36	8	1	2
Willow Oak	2							
Yellow Poplar					9			

APPENDIX 3

Importance values for the tree species by site

Species:	Site: 1	2	3	4	5	6	7	8
Black Cherry						42.81		
Black Gum	126.69	8.54		2.90	3.22			18.49
Black Jack Oak		69.40	60.10	23.93	9.36	80.04	8.96	
Black Oak	2.78			17.68	67.32	7.44	13.14	26.60
Black Willow	3.38							
Chestnut Oak				28.02				
Dogwood			17.22	9.36	6.52	3.44		2.41
Hickories	6.92	13.91		17.59	28.13	4.82		30.35
Hop Hornbeam					1.14			
Loblolly Pine	28.75	72.19	12.83	6.13	4.54	32.29	139.51	21.35
Longleaf Pine		109.04	6.33					
Post Oak	4.66		110.80	34.40	25.48	50.18	7.29	26.76
Red Maple	32.14			2.54				
Scarlet Oak			6.37					5.62
Scrub Pine - Shortleaf Pine		33.29	28.46	65.48	16.24	55.41	65.23	27.83
Sourwood				23.36	23.84	12.69	4.04	5.91
Southern Red Oak	6.66	2.17	6.50	21.81	36.20	29.40	42.75	71.29
Sweet Bay	2.67						7.89	
Sweetgum	70.62	5.44		21.20	15.46	13.37		10.79
Umbrella Tree			17.59	1.32	1.15			
Water Oak	8.97				1.17	10.80	7.33	2.59
White Oak			2.12	24.15	50.78			7.17
Willow Oak	5.53						3.74	
Yellow Poplar					9.36			

APPENDIX 4

Sorenson's Index of Similarity Values and Average Multiple "M" Values For All Twenty-eight Site Comparisons

Sites Compared	IS_s	"M"
1 - 2	42.10	1.786
1 - 3	41.67	1.867
1 - 4	59.26	1.804
1 - 5	57.14	1.783
1 - 6	60.87	1.845
1 - 7	63.64	1.736
1 - 8	61.54	1.629
2 - 3	52.63	1.465
2 - 4	54.54	1.550
2 - 5	52.17	1.791
2 - 6	55.56	1.282
2 - 7	47.06	1.287
2 - 8	47.62	1.667
3 - 4	74.07	1.313
3 - 5	71.43	1.419
3 - 6	69.56	1.107
3 - 7	54.54	1.620
3 - 8	69.23	1.512
4 - 5	83.87	1.211
4 - 6	76.92	1.128
4 - 7	56.00	1.449
4 - 8	75.86	1.310

APPENDIX 4

(Continued)

Sites Compared	IS_s	"M"
5 - 6	81.48	1.353
5 - 7	61.54	1.657
5 - 8	80.00	1.316
6 - 7	76.19	1.316
6 - 8	80.00	1.350
7 - 8	58.33	1.417

PLATE 1

GENERAL OBSERVATIONS OF SURFACE PHENOMENA ILLUSTRATED ON THE BLUE SPECTRAL BAND (.400-.480 MICRONS). NUMBERS CORRESPOND TO AREAS OF MOISTURE AND GRAIN SIZE DATA ACQUISITION.

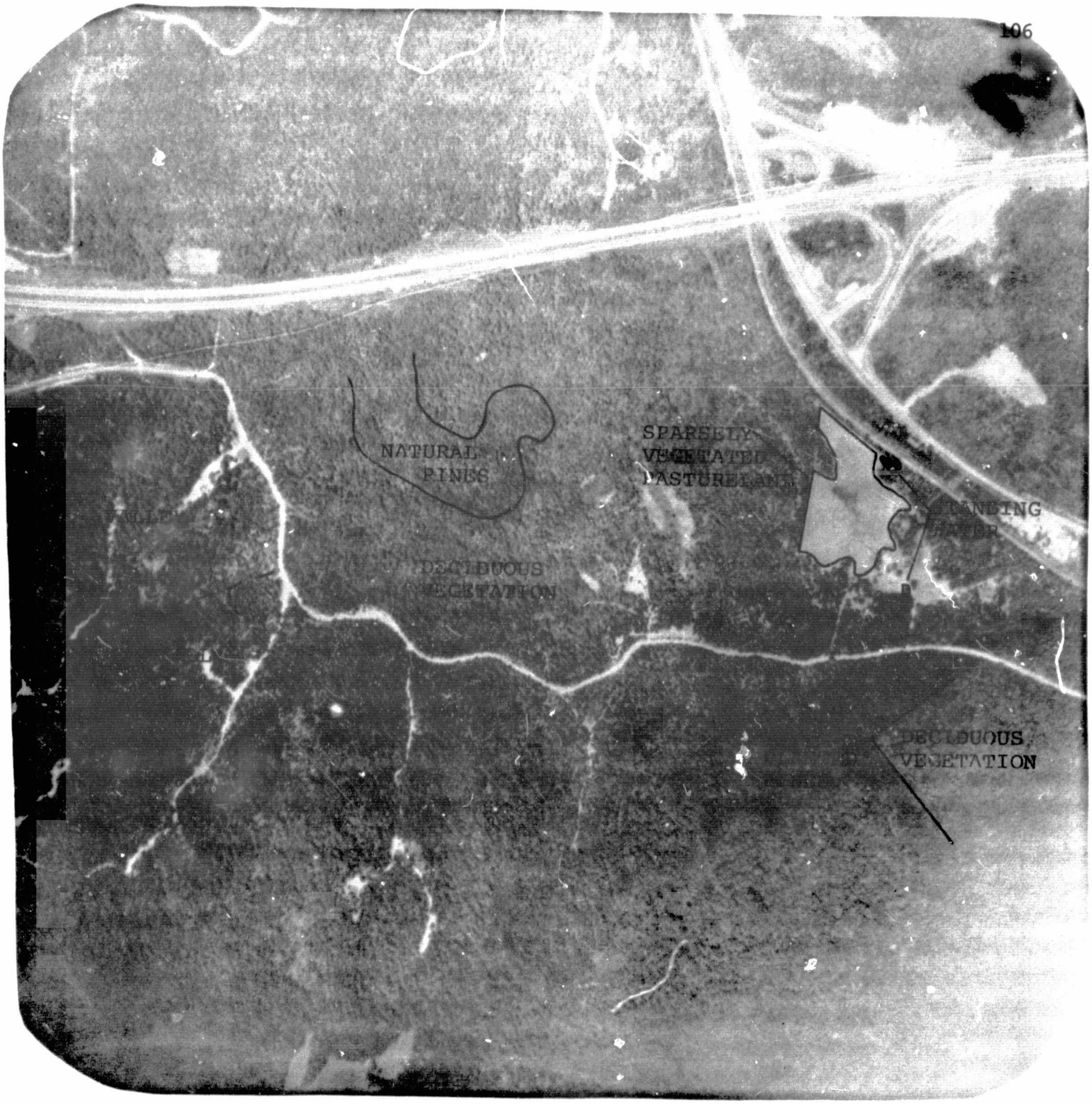

PLATE 2

GENERAL OBSERVATIONS OF SURFACE PHENOMENA ILLUSTRATED ON THE GREEN SPECTRAL BAND (.480-.590 MICRONS).

PLATE 3

GENERAL OBSERVATIONS OF SURFACE PHENOMENA ILLUSTRATED ON THE RED SPECTRAL BAND (.590-.700 MICRONS).

PLATE 4

GENERAL OBSERVATIONS OF SURFACE PHENOMENA ILLUSTRATED ON THE INFRARED SPECTRAL BAND (.730-.900 MICRONS).

PLATE 5

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE PANOTOMIC-X POSITIVE PRINT OF THE BLUE SPECTRAL BAND (.400-.480 MICRONS) IMAGE. SYMBOLS ARE AS FOLLOWS:

(1) QAL - ALLUVIUM
(2) Cpv - POTTSVILLE SANDSTONE (BEDROCK)
(3) Kck-es - SANDY LITHOLOGY OF THE EOLINE MEMBER OF THE COKER FORMATION
(4) Kck-ec - CLAY LITHOLOGY OF THE EOLINE MEMBER OF THE COKER FORMATION
(5) Kck-u - SANDY LITHOLOGY OF THE UPPER UNNAMED MEMBER OF THE COKER FORMATION

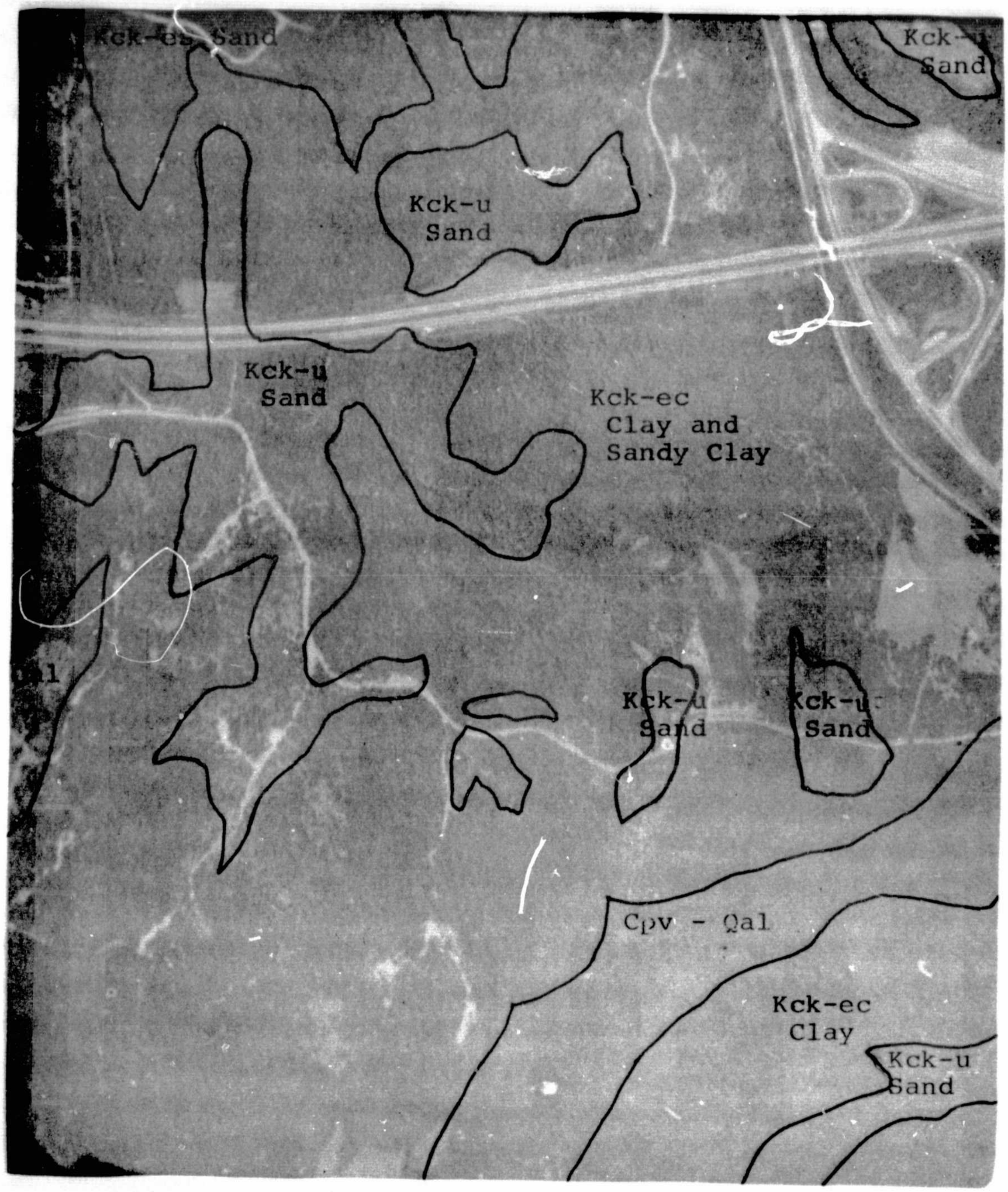

PLATE 6

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE PANOTOMIC-X POSITIVE PRINT OF THE GREEN SPECTRAL BAND (.480-.590 MICRONS) IMAGE. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

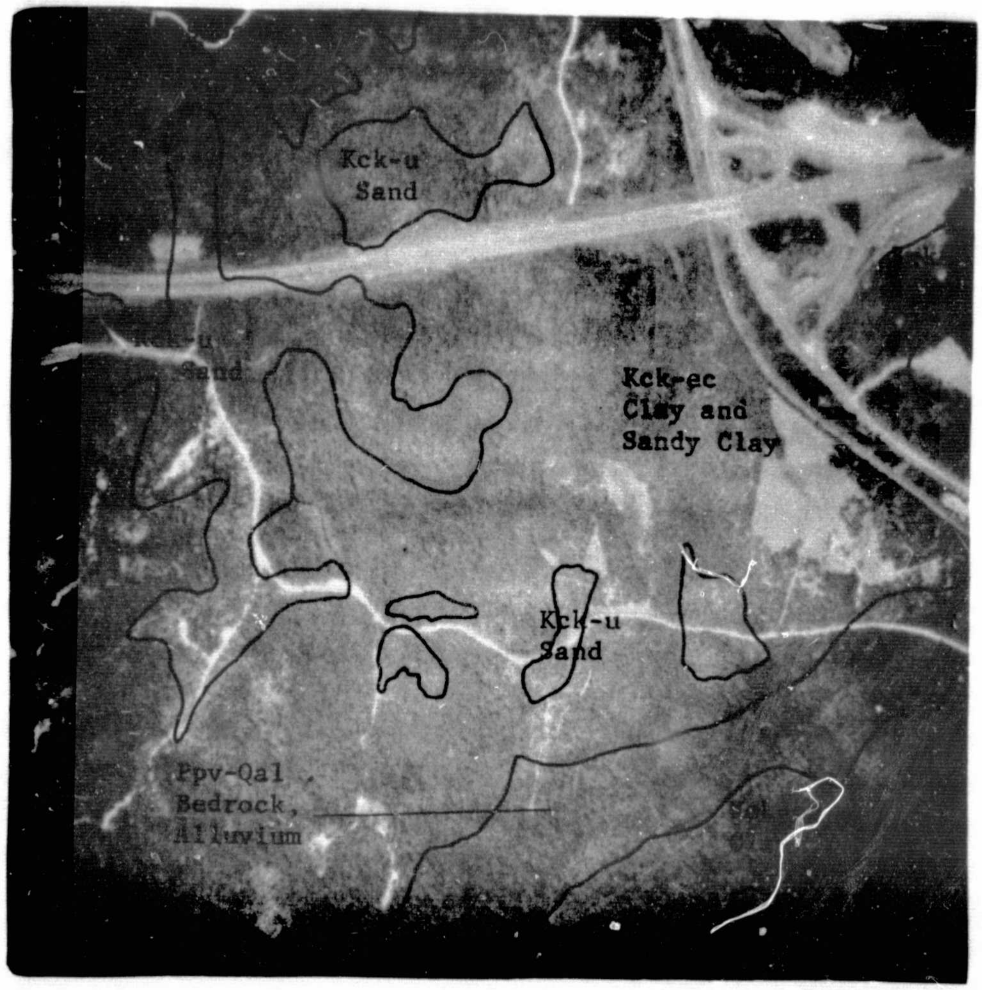

PLATE 7

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE PANOTOMIC-X POSITIVE PRINT OF THE RED SPECTRAL BAND (.590-.700 MICRONS) IMAGE. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

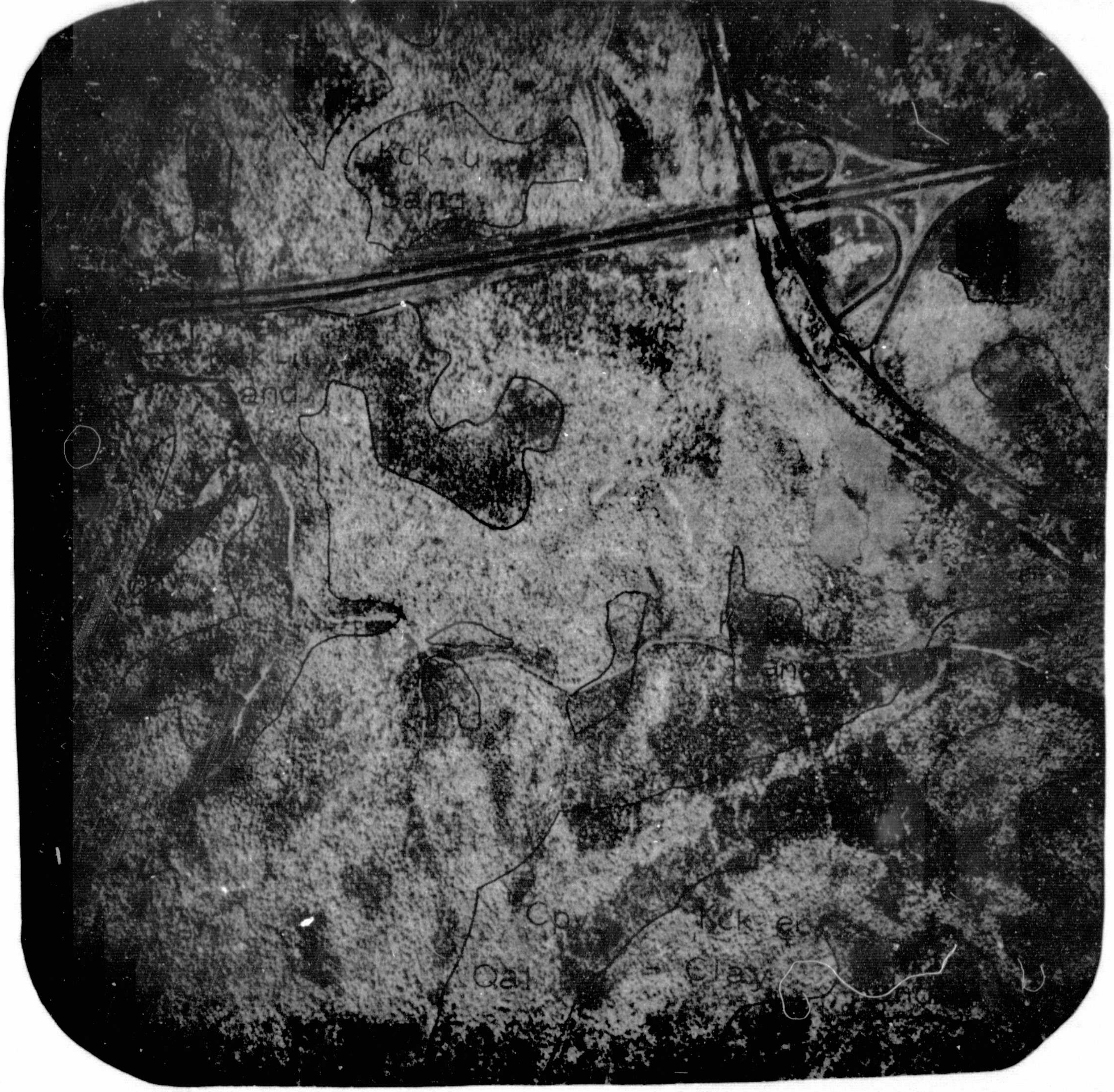

PLATE 8

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE PANOTOMIC-X POSITIVE PRINT OF THE INFRARED SPECTRAL BAND (.730-.900 MICRONS) IMAGE. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

PLATE 9

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE KODALITH POSITIVE PRINT OF THE BLUE SPECTRAL BAND (.400-.480 MICRONS) IMAGE. NOTE THE DARKENING AROUND PHOTOGRAPH EDGES. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

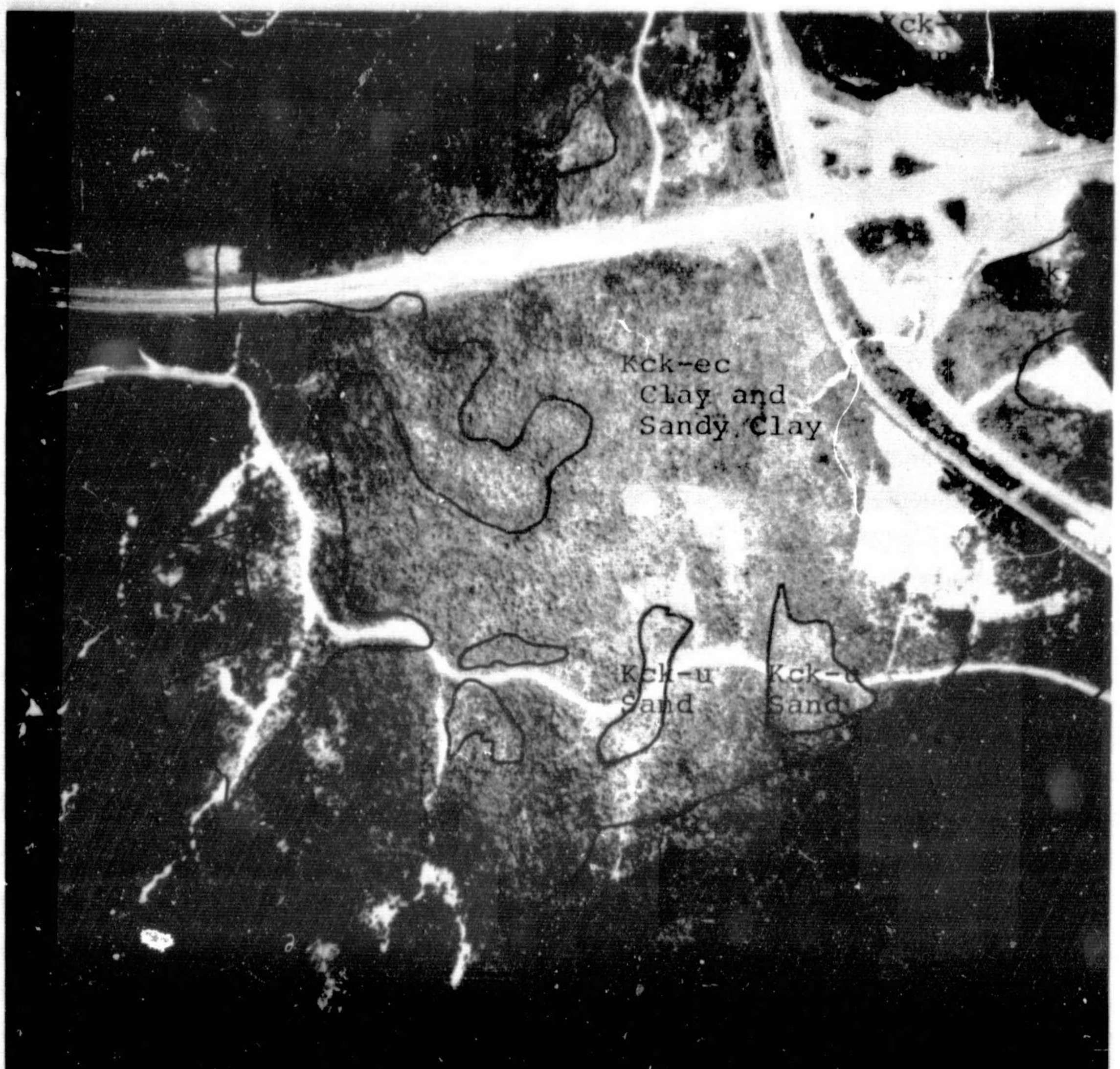

PLATE 10

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE KODALITH POSITIVE PRINT OF THE GREEN SPECTRAL BAND (.480-.590 MICRONS) IMAGE. NOTE THE DARKENING AROUND PHOTOGRAPH EDGES. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

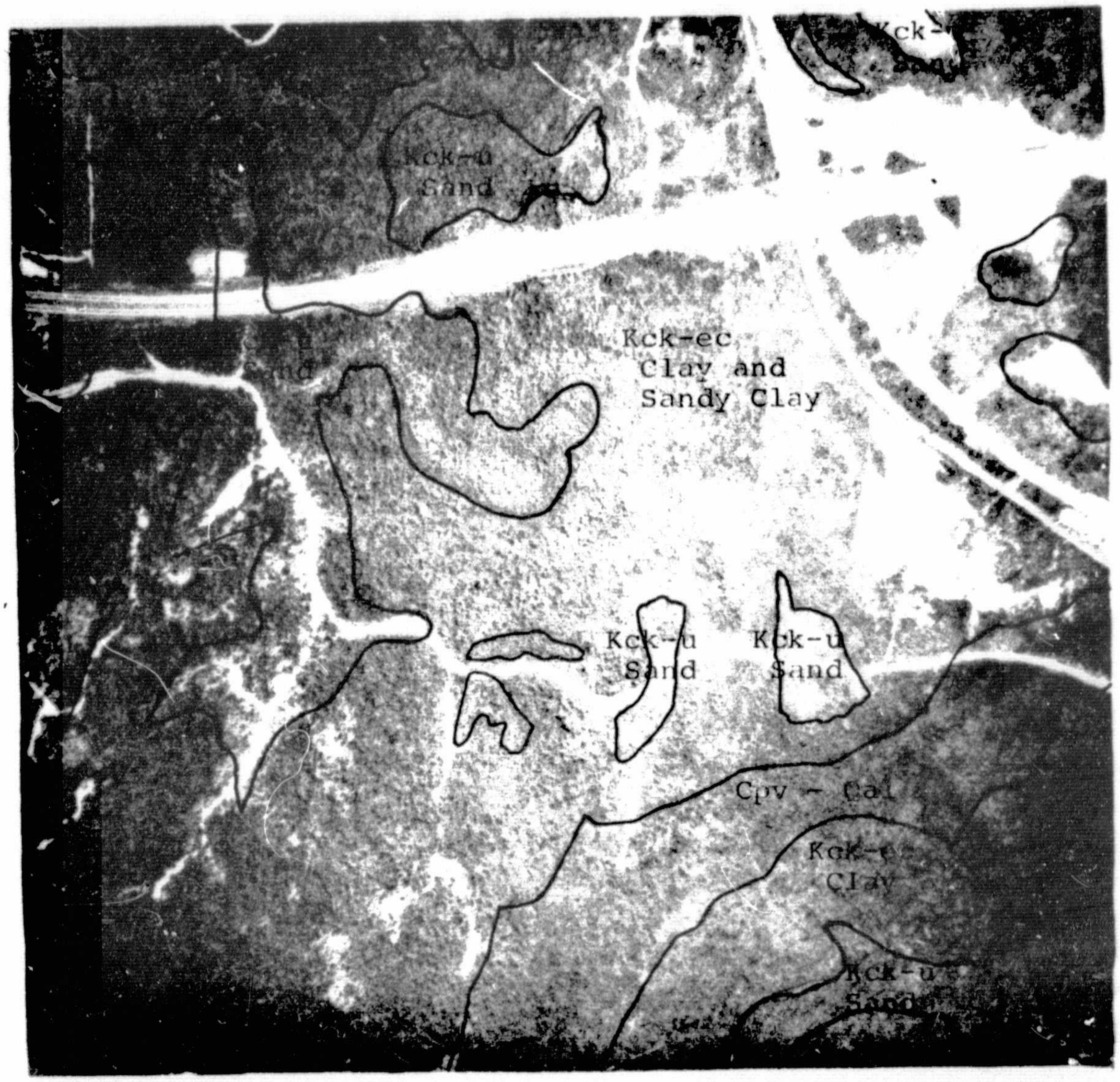

PLATE 11

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE KODALITH POSITIVE PRINT OF THE RED SPECTRAL BAND (.590-.700 MICRONS) IMAGE. NOTE THE DARKENING AROUND PHOTOGRAPH EDGES. SYMBOLS ARE THE SAME AS THOSE USED FOR PLATE 5.

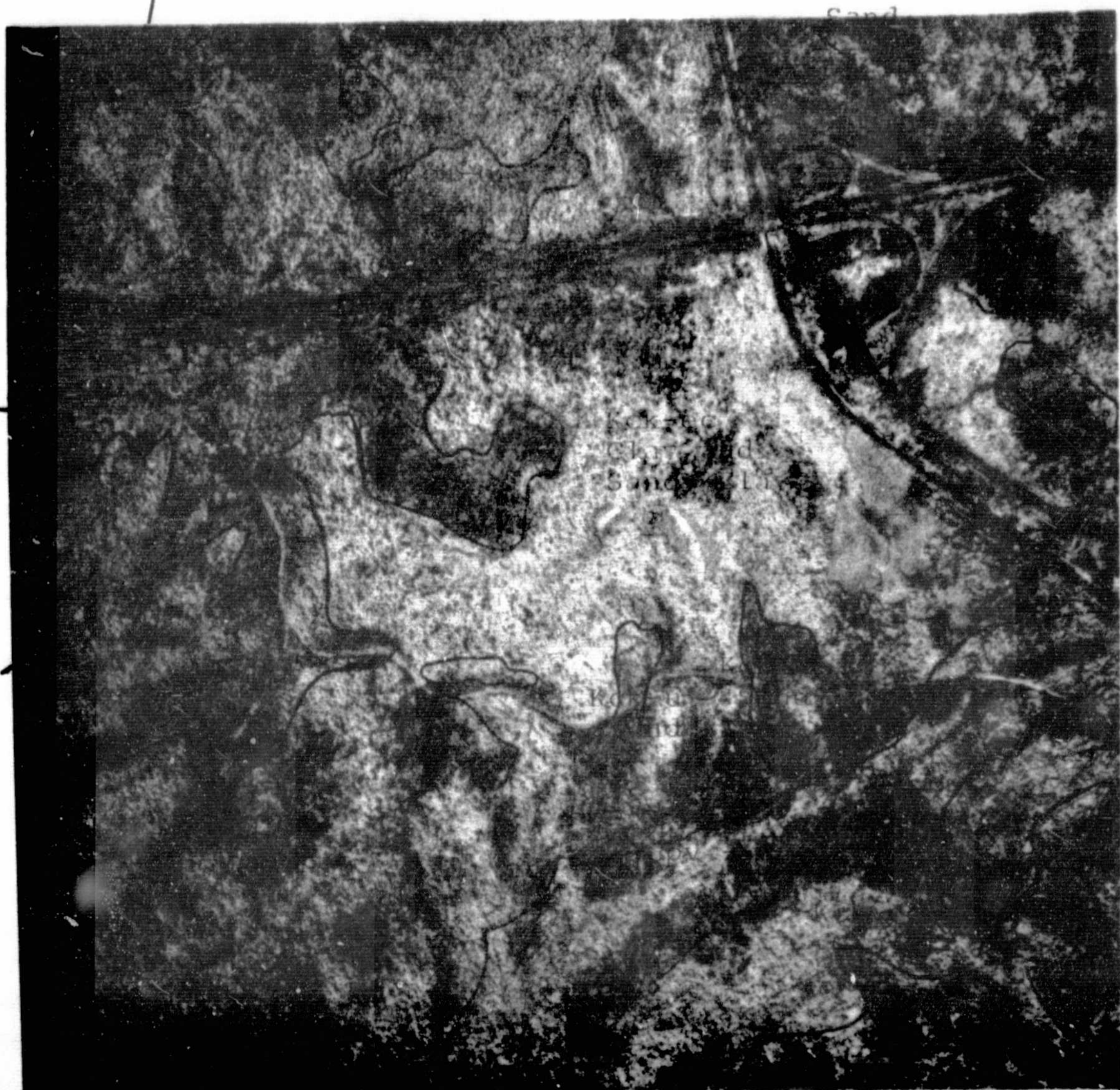

PLATE 12

COMPARISON OF DIFFERENT LITHOLOGIC UNITS IN THE COTTONDALE QUADRANGLE WITH TONAL VARIATIONS OF THE KODALITH POSITIVE PRINT OF THE INFRARED SPECTRAL BAND (.730-.900 MICRONS) IMAGE. THE OVERALL COARSE TEXTURE OF THE PHOTOGRAPH MASKS THE FINE TEXTURED AREAS EVIDENT ON PANOTOMIC-X PRINTS.

PLATE 13

BAS-RELIEF PRINT WITH NORTH-SOUTH OFFSET OF RED SPECTRAL BAND POSITIVE AND NEGATIVE TRANSPARENCIES. NOTE THE ENHANCEMENT OF EAST-WEST LINEAR TRENDS.

PLATE 14

BAS-RELIEF PRINT FORMED BY EAST - WEST OFFSET OF RED SPECTRAL BAND POSITIVE AND NEGATIVE TRANSPARENCIES. NOTE THE ENHANCEMENT OF NORTH-SOUTH LINEAR TRENDS.

PLATE 15

BAS-RELIEF PRINT FORMED BY NORTH-SOUTH OFFSET OF INFRARED SPECTRAL BAND POSITIVE AND NEGATIVE TRANSPARENCIES. NOTE THE ENHANCEMENT OF EAST-WEST LINEAR TRENDS.

PLATE 16

BAS-RELIEF PRINT FORMED BY EAST-WEST OFFSET OF INFRARED SPECTRAL BAND POSITIVE AND NEGATIVE TRANSPARENCIES. NOTE THE ENHANCEMENT OF NORTH-SOUTH LINEAR TRENDS.

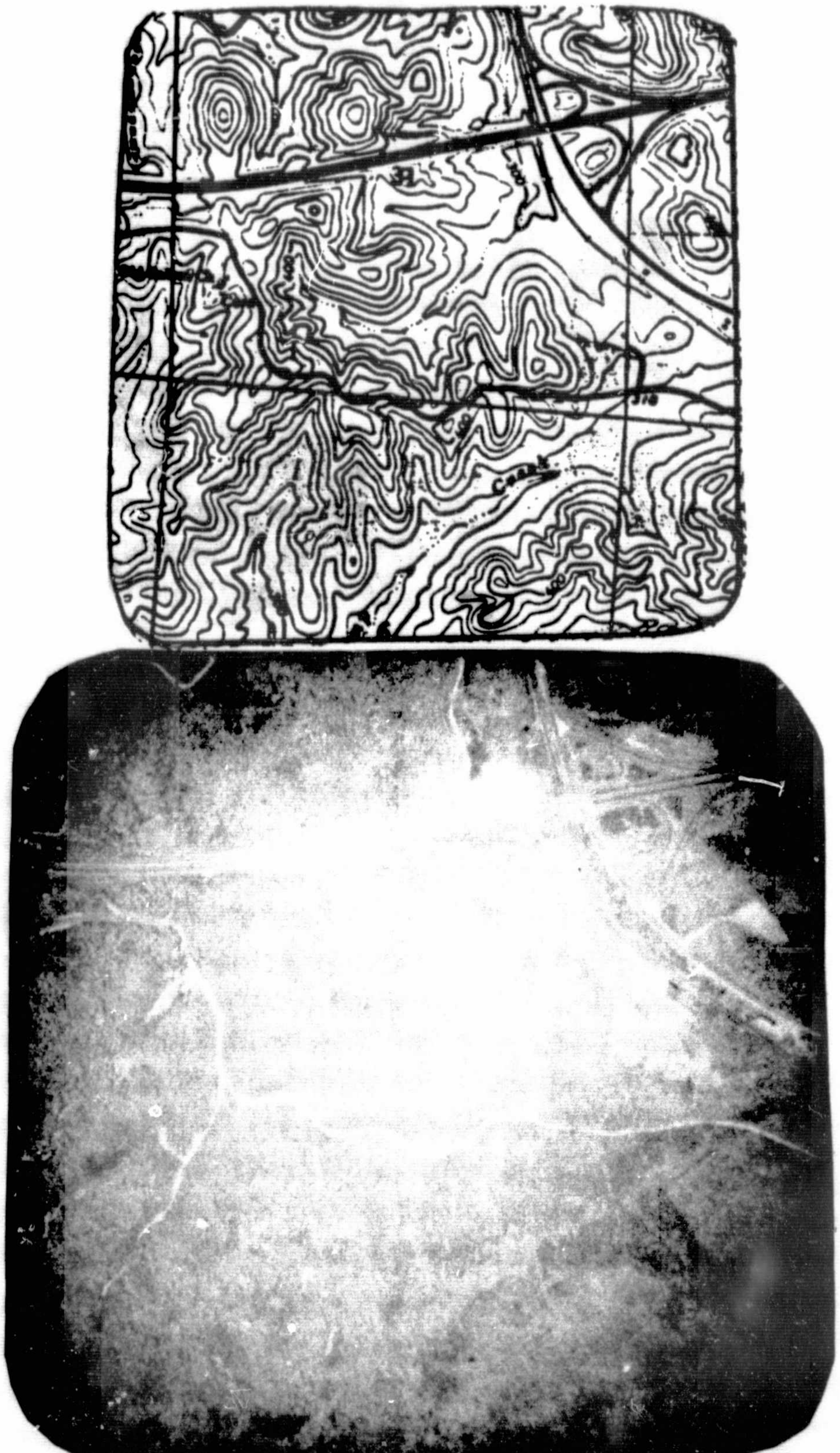

PLATE 17

TOPOGRAPHIC MAP OF STUDY AREA FOR COMPARISON WITH COLOR COMPOSITE PRINT PHOTOGRAPHED OFF AN I^2S COLOR ADDITIVE VIEWER. TONAL AND TEXTURAL VARIATIONS WITHIN THE PHOTO SHOW CLOSE CORRELATION WITH TOPOGRAPHIC DIFFERENCES, EXCEPT IN THE SOUTHWEST ¼ OF THE PRINT WHERE PLANTED PINE STANDS OCCUR. DARK AREAS CORRESPOND TO HILLTOPS WHILE LIGHTER AREAS CORRESPOND TO VALLEY BOTTOMS AND VALLEY WALLS. FILTER COMBINATIONS ARE BLUE, CLEAR, BLUE, AND BLUE RESPECTIVELY WITH THE BLUE, GREEN, RED, AND INFRARED BANDS.

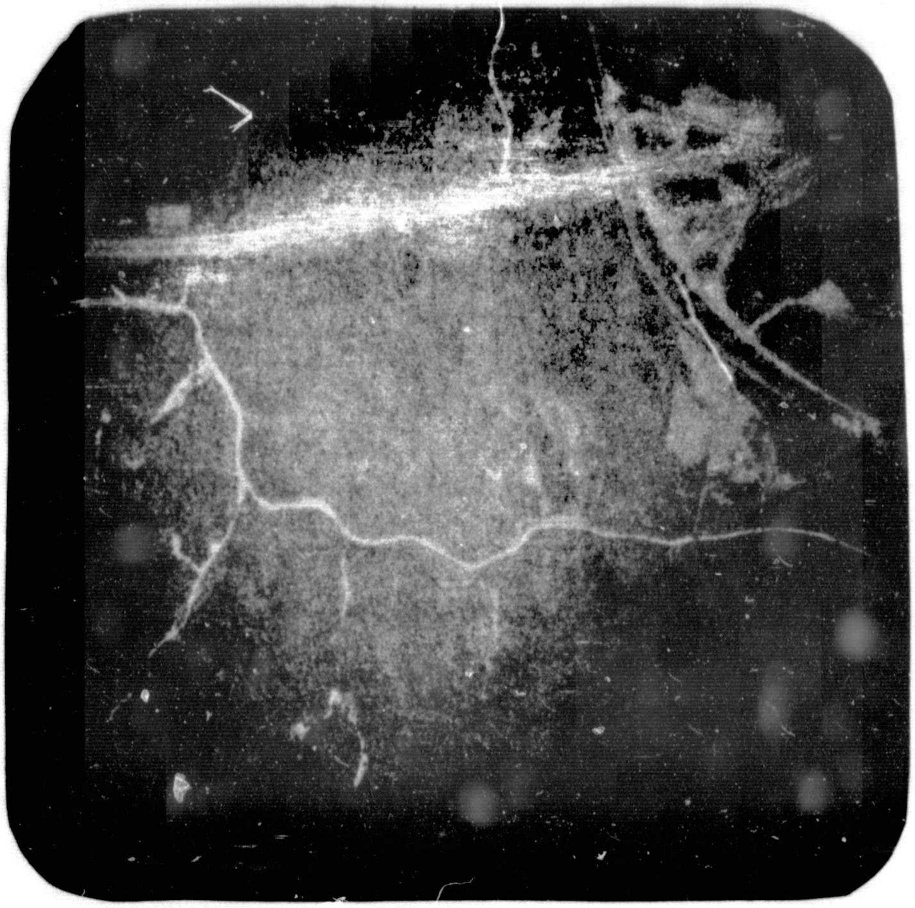

PLATE 18

COLOR COMPOSITE PRINT PHOTOGRAPHED OFF AN I^2S COLOR ADDITIVE VIEWER. CULTURAL FEATURES SUCH AS ROADS AND CLEARED AREAS ARE DISTINCT. FILTER COMBINATIONS ARE CLEAR, RED, BLUE, AND BLUE RESPECTIVELY WITH THE BLUE, GREEN, RED, AND INFRARED BANDS.

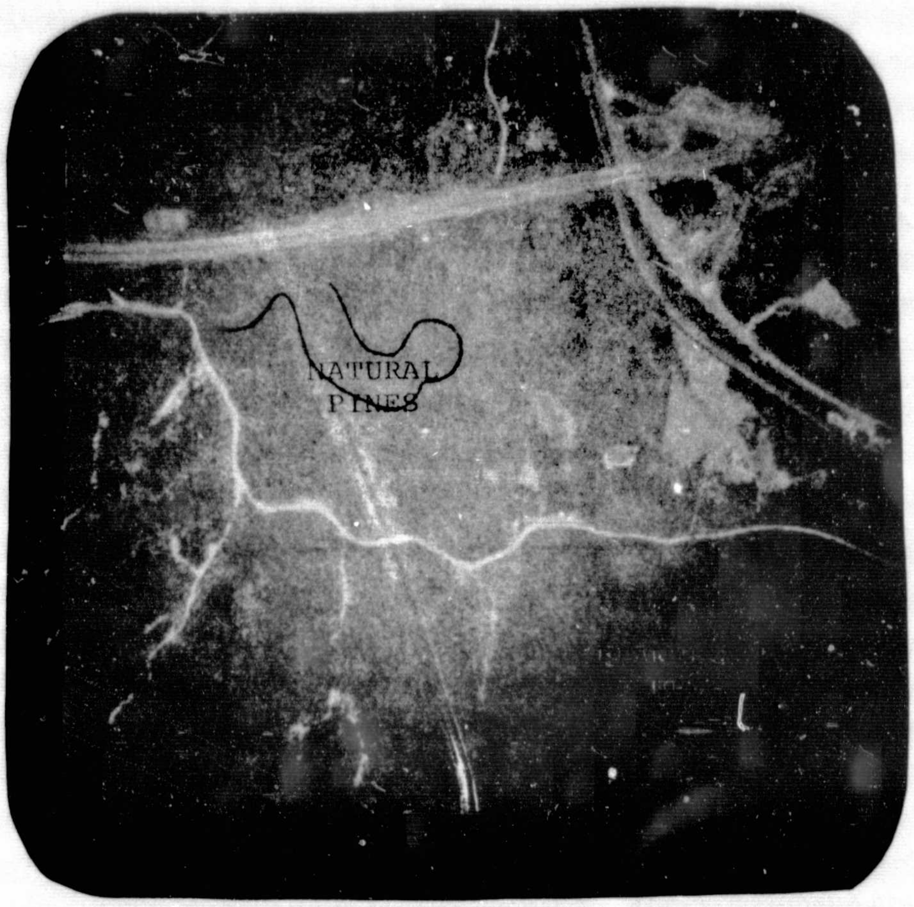

PLATE 19

COLOR COMPOSITE PRINT PHOTOGRAPHED OFF AN I^2S COLOR ADDITIVE VIEWER. NATURALLY VEGETATED PINES, PLANTED PINE STANDS AND DECIDUOUS VEGETATION ARE DISTINCT. FILTER COMBINATIONS ARE CLEAR, BLUE, RED, AND RED RESPECTIVELY WITH THE BLUE, GREEN, RED, AND INFRARED BANDS.

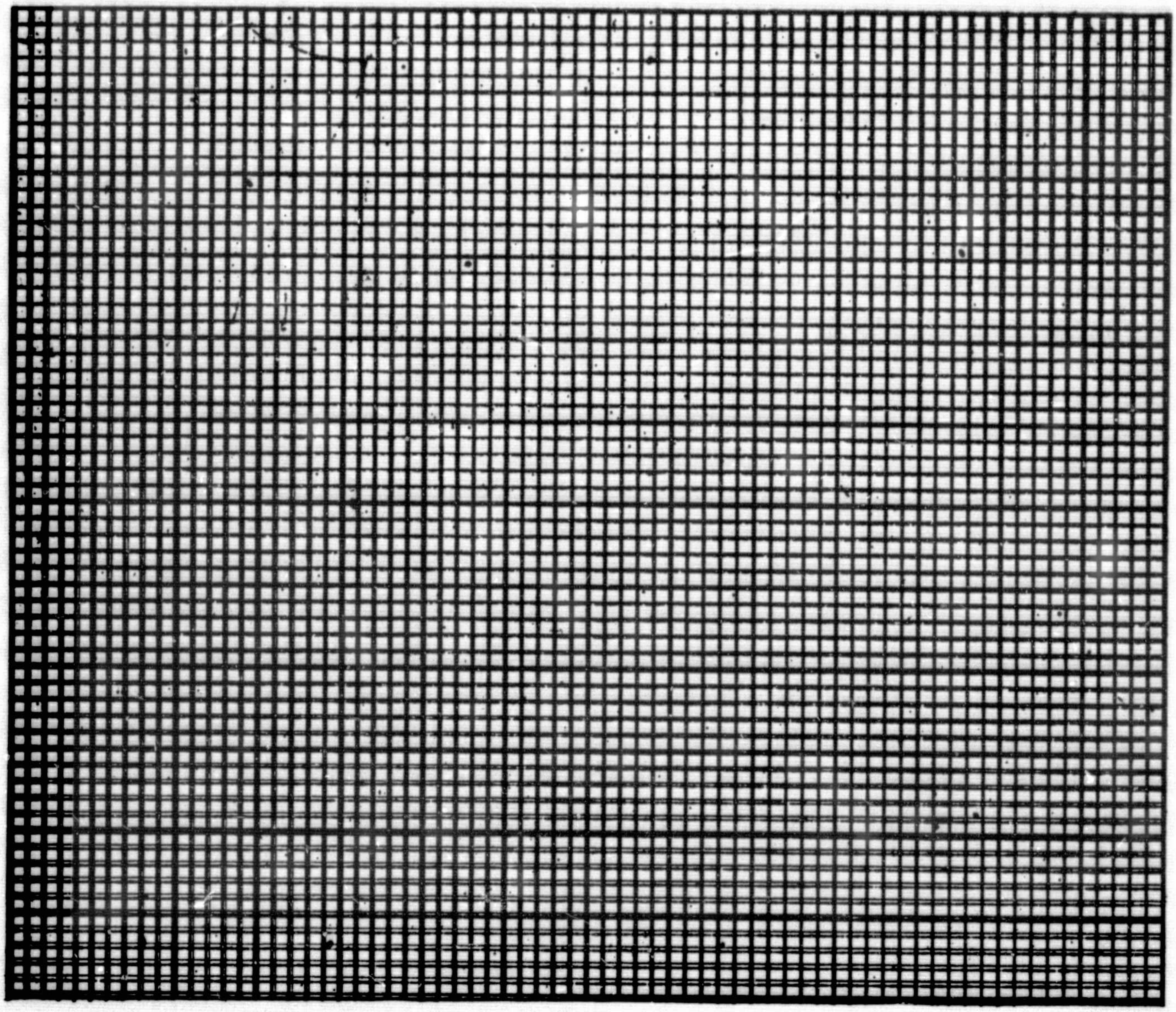

PLATE 20

THERMOFAX COPY OF 10 SQUARES TO THE INCH GRAPH PAPER SUPERIMPOSED ON ORIGINAL GRAPH. NOTE THE SLIGHT DISTORTION.

PLATE 21

THERMOFAX TOPOGRAPHIC TRANSPARENCY SUPERIMPOSED ON AN INFRARED SPECTRAL BAND PANOTOMIC-X POSITIVE PRINT. TOPOGRAPHIC TRANSPARENCIES WERE USED AS AN AID WHEN CONSTRUCTING TONAL AND TEXTURAL OVERLAYS FROM PRINTS.

PLATE 22

THERMOFAX BLACK LINE LITHOLOGIC TRANSPARENCY USED FOR CONSTRUCTING TONAL AND TEXTURAL OVERLAYS FROM PANATOMIC-X POSITIVE PRINTS. NOTE THAT THE OVERLAY DOES NOT EXACTLY MATCH THE SCALE OF THE PRINT.

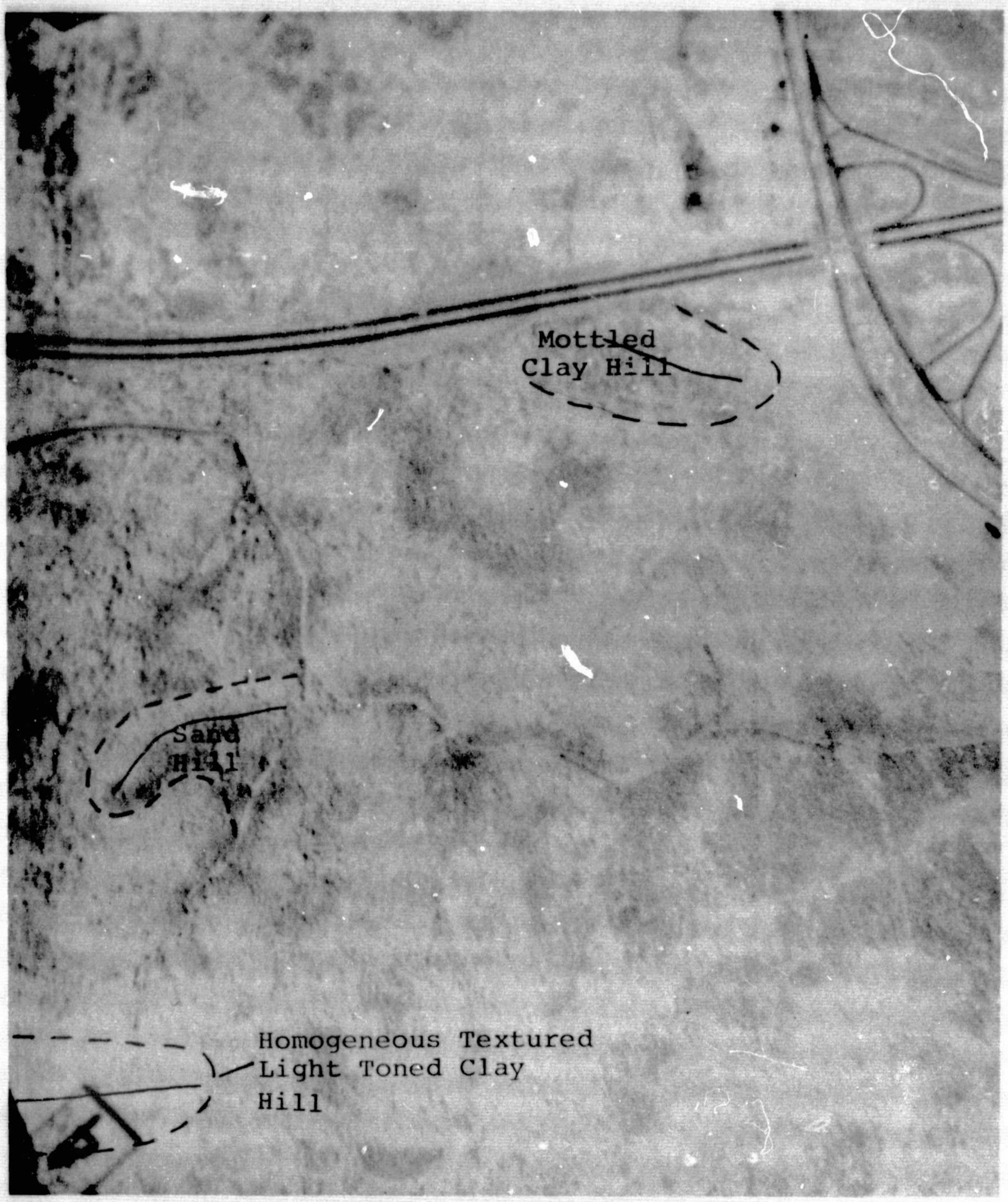

PLATE 23

INFRARED PHOTOGRAPH ILLUSTRATING SEPARATION OF TONE OF SAND HILLS. SOUTH FACING SLOPES ARE DARKER TONED THAN NORTH FACING SLOPES. ALSO, HOMOGENEOUS TEXTURED LIGHT TONED CLAY HILLS (SOUTHWEST PORTION OF PHOTO) ARE COMPARED WITH MOTTLED APPEARING CLAY HILLS (NORTHEAST PORTION OF PHOTO). LIGHTER HOMOGENEOUS TONED CLAY HILLS CAN BE DUE TO LOWER TOPOGRAPHIC POSITION, HOWEVER IN THIS CASE, THE EVEN TONE IS CAUSED BY THE SMOOTH SLOPE OF THE LAND SURFACE. THE MOTTLED CLAY HILL APPEARANCE IS CONTROLLED BY THE IRREGULAR SLOPE OF THE HILL.

PLATE 24

INFRARED PHOTOGRAPH ILLUSTRATING THE LIGHT TONED, COARSE TEXTURED, MOTTLED ALLUVIAL SIGNATURE. A DARK AREA, WITHIN THE AREA OF ALLUVIAL SIGNATURE, LIES IN THE SOUTHEASTERN PORTION OF THE PHOTOGRAPH. THIS DARK AREA IS CAUSED BY LOW REFLECTANCE ASSOCIATED WITH SWAMPY AREAS BORDERING THE CONFLUENCE OF TWO CREEKS.

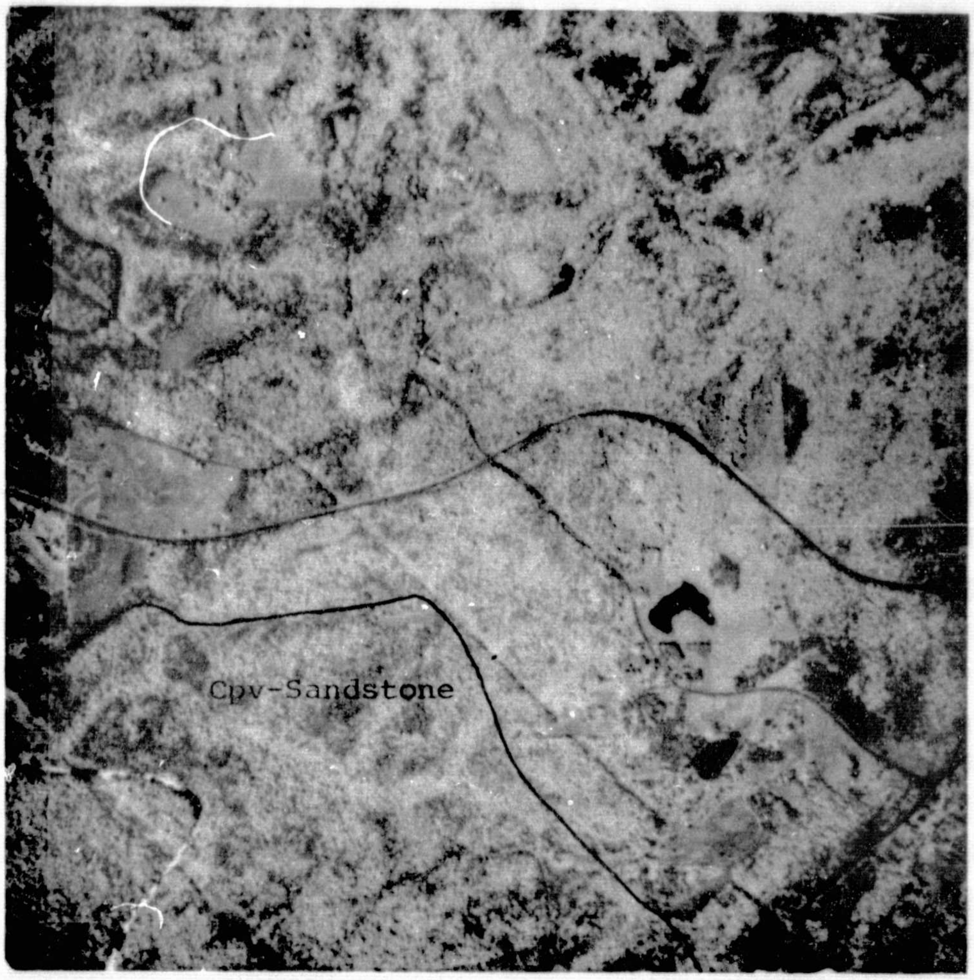

PLATE 25

INFRARED PHOTOGRAPH ILLUSTRATING THE CHARACTERISTIC COARSE TEXTURED LIGHT AND DARK MOTTLED SIGNATURE FOR INDURATED SANDSTONE. THIS TONAL AND TEXTURAL SIGNATURE IS CONTROLLED BY THE SLOPE IRREGULARITY ASSOCIATED WITH THE FINE TEXTURED DRAINAGE IN THE AREA.

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FLOOD HAZARD MAPPING

Introduction

The general public as well as the scientific community is quite familiar with the potential dangers and costs of the development of flood-prone areas. Flood-prone areas, which are generally flat, represent extremely attractive land for development. Without adequate mapping programs and zoning restrictions, unregulated development of flood-prone areas can occur. Annual loss to flooding in this country often exceeds $1.5 billion dollars (Todd, 1970); moreover, it has been estimated that over 12% of our populace lives in flood-prone areas and that this figure is growing at a rate greater than population increase (Sewell, 1969; White, et.al. 1958).

With these figures in mind it is obvious that the demand for flood-prone hazard mapping is great and will continue to increase as population and urbanization increase for it is projected that by the year 1990, 90% of this country's populace will live in urban areas (Legget, 1974). A variety of techniques have historically been used for flood plain mapping. These include the use of physiography, soils, vegetation, the occasional flood, the regional flood of selected frequency, and, the most accurate method--flood profiling and determination of backwater curves. The cost of flood area mapping is variable but generally expensive and has been estimated by Wolman (1971) to be as great as

thousands of dollars per km. of river. The multi-band spectral capabilities of remote sensing techniques offer the potential for large scale mapping of flood-prone areas at a speed which is more rapid and a cost which is less than standard mapping techniques. This project has dealt with the development of the uses of remote sensing techniques for flood hazard mapping.

During the fall and winter of 1972 and 1973 the heavy rains, which caused flooding in the lower Mississippi Valley, also caused extensive flooding in some of the river systems of Alabama, especially on the Tombigbee and Mobile Rivers of western and southwestern Alabama. The area of study for this project is seen in figure 1. Significant innundation of the land began on or about December 20 at Mt. Vernon, north of Mobile Bay and persisted in this area throughout the spring months. At Coffeeville on the Tombigbee River, innundation of the land began around January 15th. ERTS imagery of the area, pictured on two successive frames and obtained on an 18-day sequential basis from October 15, 1972 to January 15, 1973 and high altitude color infrared imagery flown on September 24, 1972 at a height of 18,000 meters, reveal very interesting and potentially economically useful dark tonal anomalies which can aid in flood-prone area mapping and can serve as a means for the verification of existing flood hazard maps.

Objectives

The objectives of this study are multifold. They are, specifically:

1. to determine if ERTS and U-2 imagery can be useful for mapping of flooded and flood-prone areas,

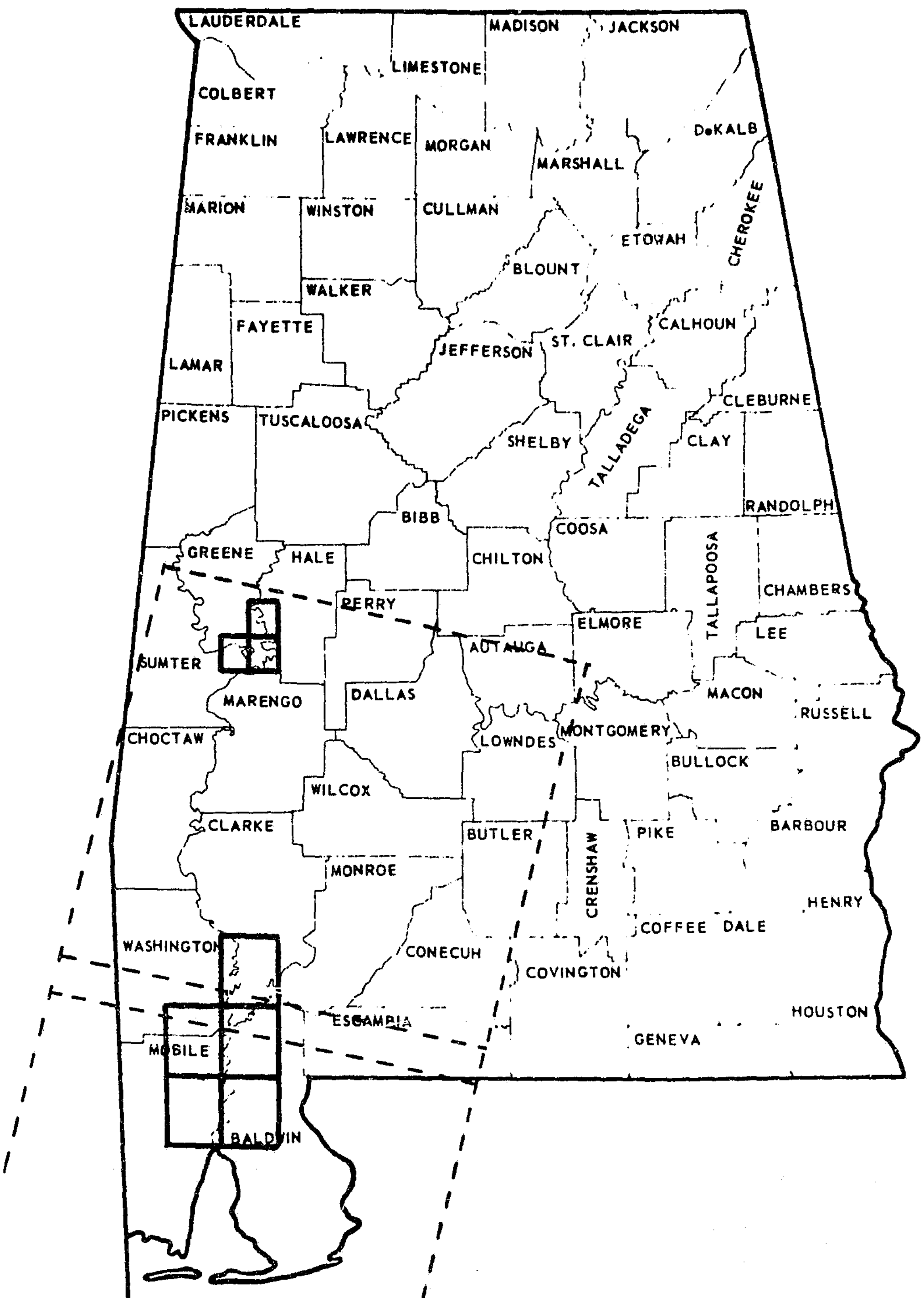

FIGURE 1

Area of study for flood-hazard mapping. Two ERTS scenes are outlined by dashed lines and quadrangles with USGS flood hazard data are indicated.

2. to determine if ERTS and U-2 imagery can be used for the verification of existing flood-prone maps,
3. to determine the greatest scale at which ERTS and U-2 imagery can be used for flood area studies,
4. to examine the cost of remote sensing mapping versus standard techniques for flood-prone mapping, and
5. to relate flood-prone areas as seen on ERTS images to those seen on high altitude underflight (U-2) imagery.

Methods

This study has involved use of only the multispectral scanner imagery from the ERTS satellite and color infrared imagery from U-2 flights; no RBV imagery has been used. All four ERTS multispectral scanner bands have been examined but the extensive work has been done only on band 7 (0.8-1.1 microns). The ERTS images have been expanded by photo enlargement to scales of 1:250,000 and 1:100,000 and the U-2 images to a scale of 1:62,500 in order to map the flood hazard areas. The accuracy of the mapping was determined by a geometric comparison of ERTS flood hazard areas with those mapped by the U.S.G.S. Standard U.S.G.S. flood hazard maps, where available, were used. The alignment of imagery and U.S.G.S. data was made at the above scales through the coordination of known geographical points. The January 15, 1973 ERTS imagery has been used for most of the work. These scenes were

chosen because they are largely cloud free and the imagery was taken during innundation of the land. Also, in order to see if flood-prone areas could be delineated prior to flooding, the October 17, 1972 scene (band 7) of the Mobile Bay area was examined.

Band Selection

Flood plains appear as dark low reflectance tonal anomalies on the infrared bands of ERTS imagery. The reasons for this are discussed in a later section of this report. The tonal anomaly signatures are not as distinct on multispectral scanner bands 4 (0.5-0.6 microns-green) and 5 (0.6-0.7 microns-red) (figures 2 and 3, respectively) as they are on the bands 6 (0.6-0.8 microns-near infrared) and 7 (0.8-1.1 microns-near infrared) (figures 4 and 5, respectively). A visual comparison of the dark tonal anomalies on Bands 6 and 7 indicates that probably either of these images could be used in the delineation of flood hazard areas but the visual estimate shows that the flood hazard areas represent a higher contrast target on the band 7, rather than the band 6, imagery. Therefore, multispectral scanner band 7 has been used in all of the following examinations with the assumption that no greater accuracy could be obtained from the use of band 6 imagery. Band 7 is also known to penetrate thin clouds, yield excellent land/water delineation and give superior natural feature definition (Emplaincourt and Wielchowsky, 1974).

FIGURE 2
January 15, 1973 ERTS image of Mobile Bay area, Alabama - band 4

FIGURE 3

January 15, 1973 ERTS image of Mobile Bay area, Alabama - band 5

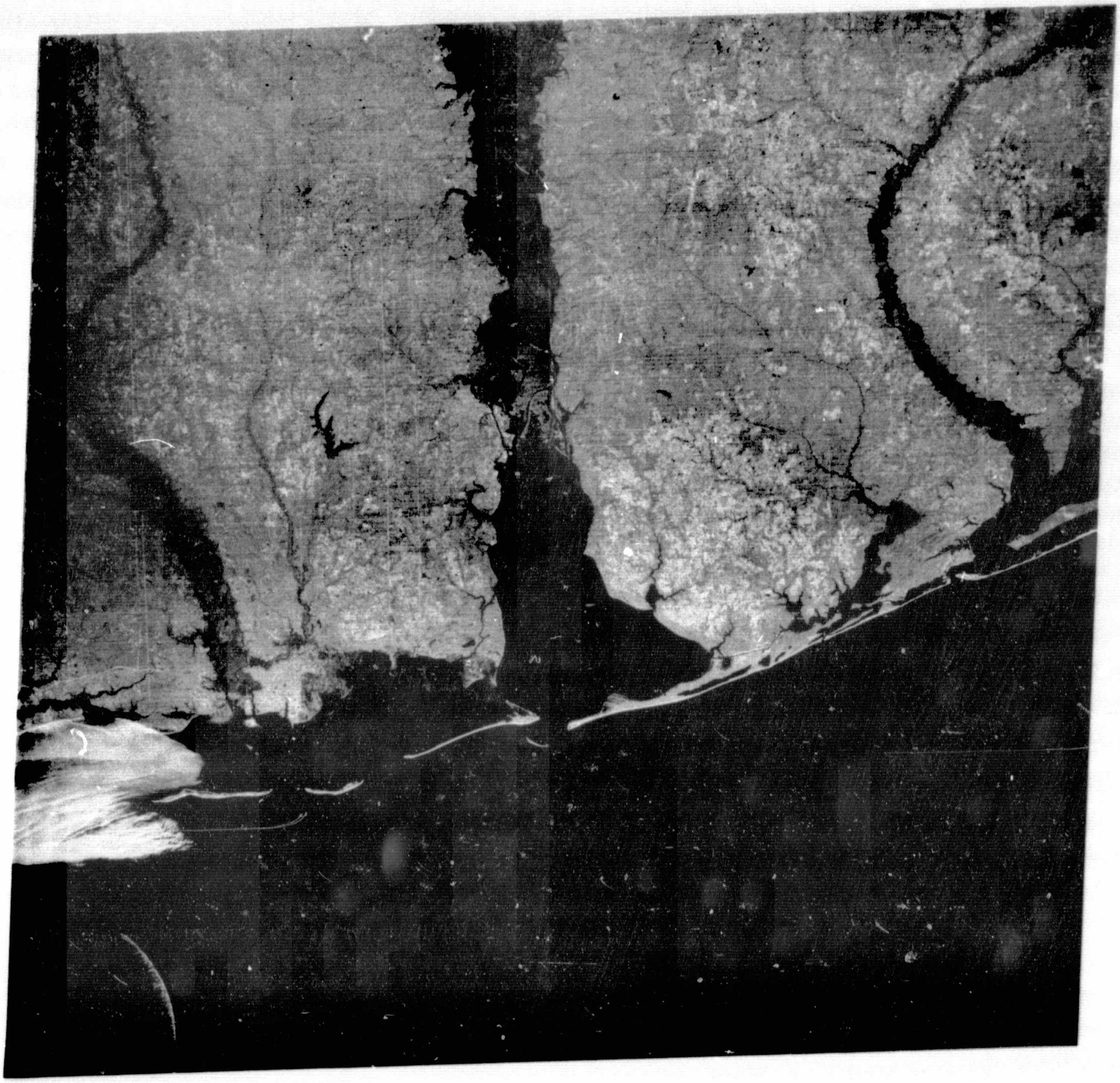

FIGURE 4

January 15, 1973 ERTS image of Mobile Bay area, Alabama - band 6

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FIGURE 5

January 15, 1973 ERTS image of Mobile Bay area, Alabama - band 7

Delineation of Flood Hazard Areas and Correlation of ERTS and U.S.G.S. Data

Scale 1:250,000

The Southern Scene

Figure 5 is the band 7 ERTS scene of the Mobile Bay and northern environs taken after initial innundation of the land on December 20, 1972. The river systems which empty into the northern end of the Bay are the Mobile, the Tensaw, the Blakely, the Spanish and the Appalachee. The flood plains of these river systems appear extremely dark and are easily differentiated from non-flooded areas in most places. Few flood plain features, such as levees, back swamps, etc. can be differentiated, but there is really little need for such differentiation since the delineation of the flooded areas is so distinct on this scene.

Most of this flooded area is covered by standard 15-minute U.S.G.S. flood hazard maps, drawn on the basis of the 100-year recurrence interval flood. Correlation between ERTS data and ground truth (U.S.G.S. maps) is therefore possible for most of this scene. The region just immediately north of Mobile Bay is not covered by existing flood hazard maps.

The next figure (6) represents the correlation between the ERTS and the U.S.G.S. data. The original scale for this correlation was at 1:250,000 and the names for the flood hazard quadrangle maps are noted within the map area. The areas of disagreement between the ERTS and U.S.G.S. data are noted in black. The areas of disagreement generally result from the fact that the U.S.G.S. data show a larger flood hazard area than do

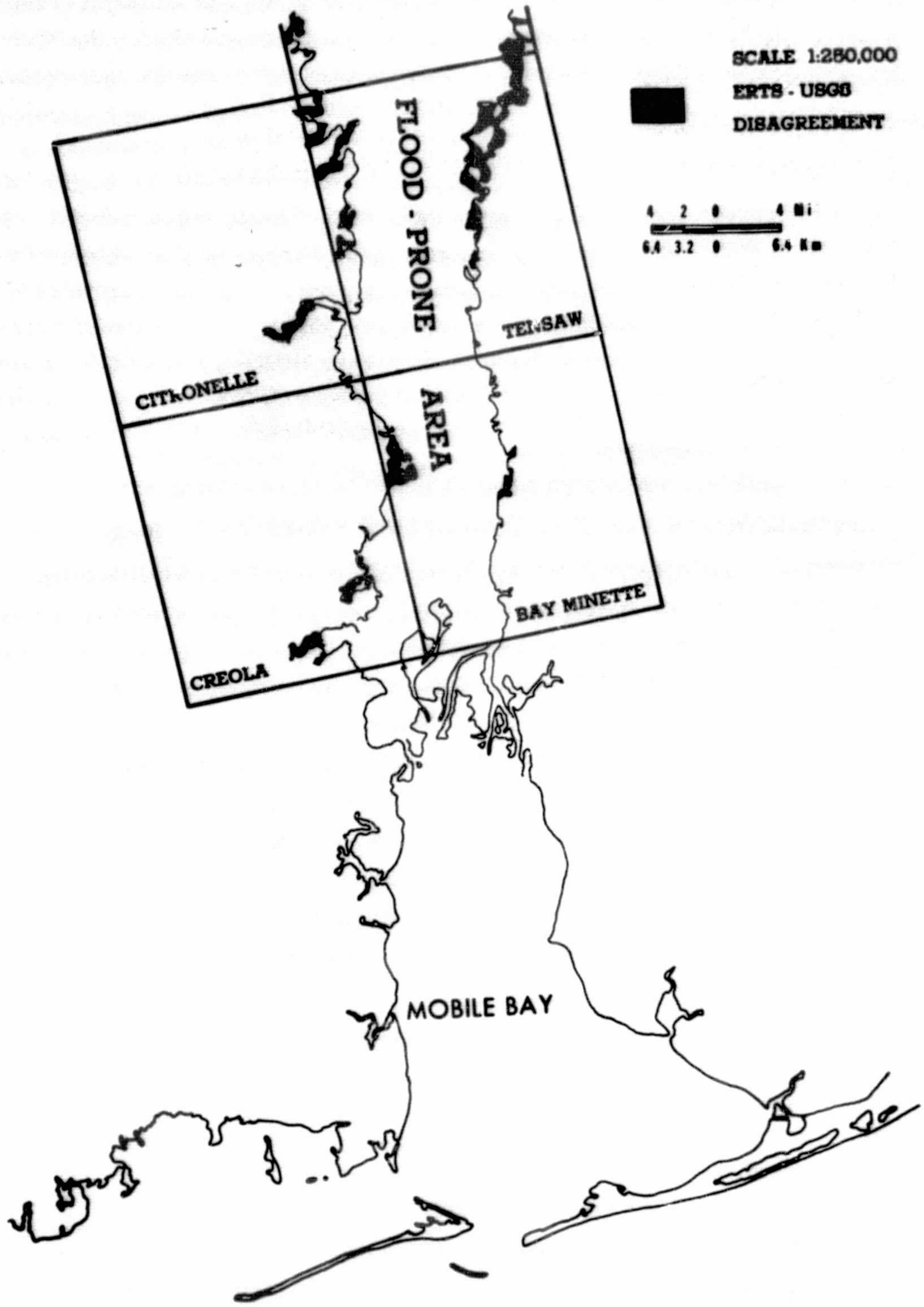

FIGURE 6
Correlation between USGS flood hazard data and ERTS (January 15, 1973 MSS band 7) flood hazard data for the southern scene. The origiral correlation was made at 1:250,000 scale.

the ERTS data. Planimeter measurement indicates, however, an agreement between the two sets of data for over 97% of the area.

The areas of disagreement can generally be explained. The flood recurrence interval for the 1972-1973 flood was about 30 years at the Mt. Vernon station north of Mobile Bay (U.S. Army Corps of Engineers, personal communication on February 1, 1974); the U.S.G.S. maps are drawn to indicate flood hazard areas on a 100-year recurrence interval. Therefore, complete correlation is not expected, especially in areas along the edge of the flood plain where topography rises relatively steeply and resists the lesser recurrence interval flood such as that which occurred during the ERTS overflight. Also in the two western-most quadrangles, the Creola and the Citronelle, areas of disagreement correspond generally to small flood-prone streams. These streams rise quite steeply to their heads which may be 50 to 70 meters above sea level. Since the flood waters of the major river systems originated from northern Alabama and not locally it is not expected that the small streams rising to the west out of the flood-prone area would be flooded and discrepancies between U.S.G.S. data and ERTS data can be explained on this basis. One large area of disagreement occurs in the Tensaw Quadrangle on the eastern side of the flood-prone area. The exact reasons for this disagreement are not fully known yet; U-2 imagery of the area (flown on February 2, 1973) has been examined with the thought that flood control facilities may have been constructed since printing of the flood-prone area map for the Tensaw Quadrangle (1970). No flood control structures were observed.

The Northern Scene

The northern ERTS scene is shown in figure 7. The southern portion of this scene overlaps with the ERTS imagery described above. The dark tonal anomalies for the flood plains of the Tombigbee and Alabama Rivers are distinct in the southern portion but become less easily delineated in the northern portion, especially near the junction of the Tombigbee and Warrior Rivers. Many fluvial phenomena are easily noted in this image; abandoned river channels, swamps, natural levees and land use patterns can be used to delineate apparent flood-prone areas as complementary inputs to the tonal anomalies which characterized the flood hazard regions. Considerable difficulty was experienced, however, in the differentiation of the flood plains when the tonal anomalies were faint and when the flood plains appeared as low contrast targets. Note the areas about 15 kilometers south of the Tombigbee--Black Warrior River junction in figure 7. Topographic coverage (the Jefferson and Myrtlewood North Quadrangles) was used as an aid in the determination of what represents a flood-prone area in this region south of the river junction. It was found that the mere existence of abandoned stream channels does not necessarily indicate flood-prone areas in this region. Areas in the Selma Chalk (Jefferson Quadrangle), which topographically are at least 23 meters above the Tombigbee River and not interpreted to be flood-prone on the basis of their elevation, have signature characteristics very similar to the characteristics of lower flood-prone areas 15 meters above the river. The nonflood-prone areas do appear to be slightly lighter in color, presumably reflecting more cleared land and different land use, when compared

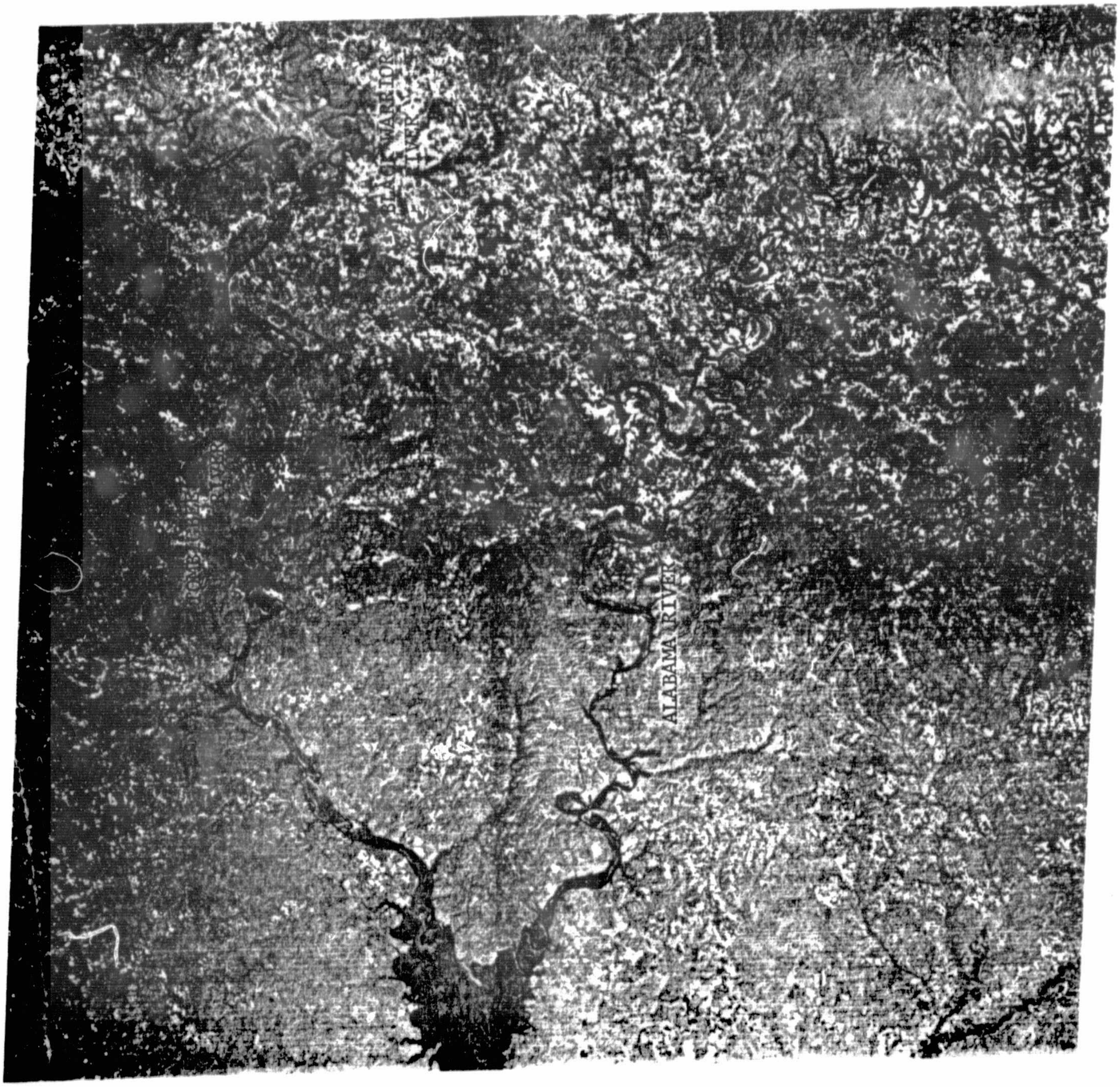

FIGURE 7
January 15, 1973 image of the northern scene - multispectral scanner band 7.

to the flood-prone areas. These higher abandoned stream channels may be Pleistocene in age, now lying 23 or more meters above the river level in the nonflood-prone areas. Careful observation of tonal anomalies, swamps, levees, backwater areas and use of topographic coverage, where available, can therefore be used to map apparent flood-prone areas throughout the northern portion of this scene.

The correlation of the ERTS and U.S.G.S. data is shown in figure 8. The original scale of this comparison was made at 1:250,000. In addition to those quadrangles noted above for the southern scene, overlapping in this scene, only 3 additional quadrangles are available with flood-prone hazard data. These quadrangles are 7.5 minute sheets: the Mason Bend, the McDowell and the Demopolis. The correlation between the ERTS and U.S.G.S. data in the southern portion of this scene, enlarged in figure 9, is quite good and discrepancies are essentially the same as those denoted earlier for the southern scene. This figure presents information for the Choctaw Bluff quadrangle, not included in the previously discussed southern ERTS scene.

In the northern portion, enlarged in figure 10, where flood plains are less distinct, the correlations, although in broad agreement, are poorer than elsewhere. As above, ERTS flood areas were not as extensive as U.S.G.S. areas and the ERTS data correlate for 83% of the U.S.G.S. areas. No flood crest data are available for the Tombigbee--Black Warrior junction region; data for Coffeeville, about 150 kilometers to the south, indicate that the flood crest passed on January 15 at Coffeeville (figure 7), the date of the ERTS image. Therefore, it could be assumed that the

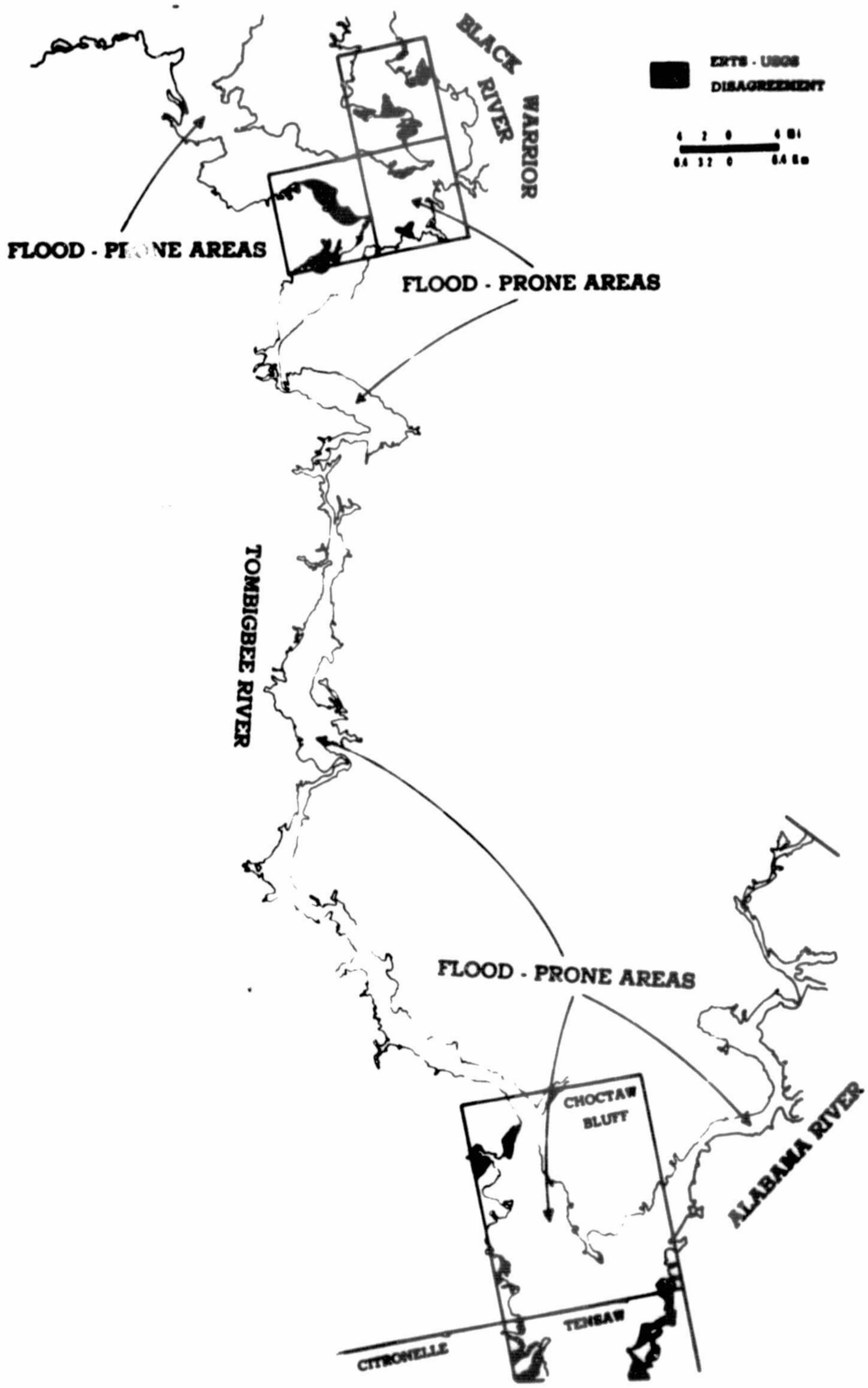

FIGURE 8

Correlation between USGS flood hazard data and ERTS (January 15, MSS band 7) flood hazard data for the northern scene. The original correlation was made at a scale of 1:250,000.

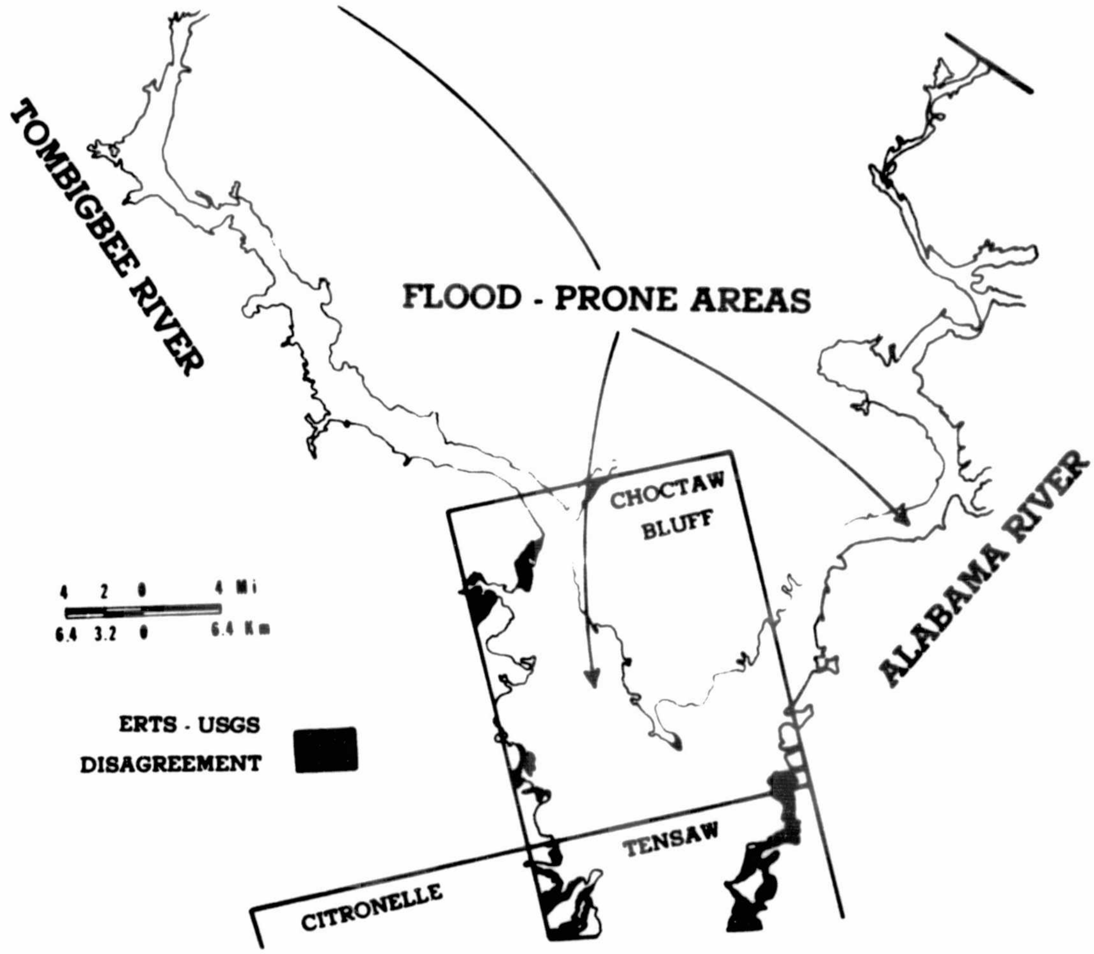

FIGURE 9
Enlargement of the southern portion of figure 8 . Original correlation was made at a scale of 1: 250, 000

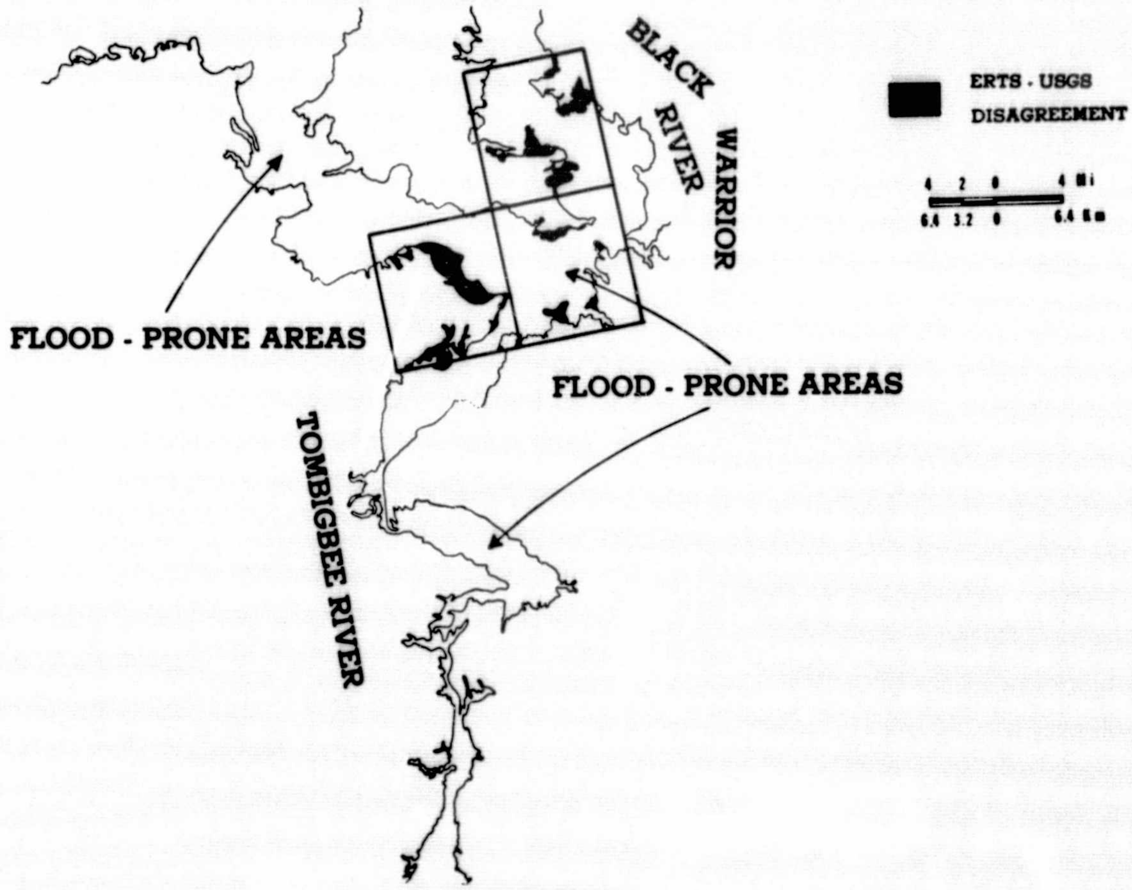

FIGURE 10
Enlargement of the northern portion of figure 8 . The original correlation was made at a scale of 1;250, 000

flood crest at the Tombigbee--Black Warrior River junction occurred prior to January 15 and, therefore, the tonal anomalies were not highly distinct on January 15 at the rivers' junction. Also, the flooding in the Tombigbee--Black Warrior River area was of a 30-year recurrence interval (U.S.G.S., James Daniels, personal communication). Therefore, the correlations between ERTS and U.S.G.S data (100-year recurrence interval) would not be expected to be perfect, with ERTS images showing less extensive flood-prone areas than do the U.S.G.S. maps.

South of the rivers' junction no flood hazard maps exist and tonal anomalies are fairly distinct; flood hazard areas have been mapped (scale 1:250,000) from the ERTS January 15 image and are shown in figures 8, 9, and 10. Owing to the good tonal anomalies in this area, aided by geomorphological features, the delineation of flood-prone hazard areas here is considered to be accurate for this flood and at a scale of 1:250,000.

Scale 1:100,000

The potential use of ERTS data at a scale of 1:100,000 for flood-hazard mapping was also examined for the southern scene. The relationship between ERTS and U.S.G.S. data is shown in figure 11. Generally the correlations at this scale appear good and the disagreements are similar to those noted above for the 1:250,000 scale on the order of 450-600 meters in lateral extent. A few large areas of disagreement exist which are apparently due to the fact that this represents a 30-year, rather than a 100-year, flood. The accurate and reliable use of the ERTS data at a scale of 1:100,000 is, however, questioned for the following reasons (Welch, 1973; Colvocoresses and McEwen, 1973);

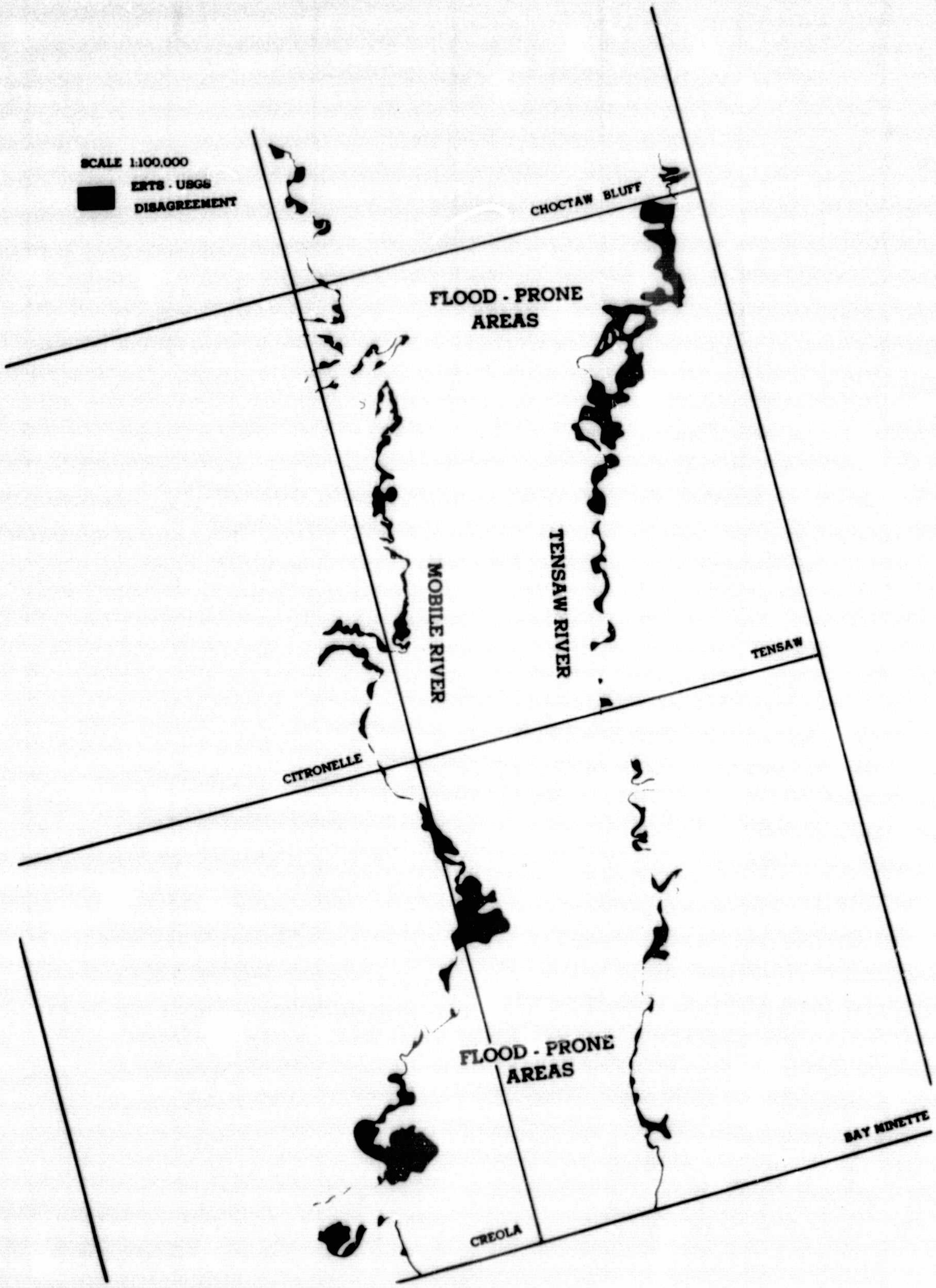

FIGURE 11
Correlation between USGS flood hazard data and ERTS (January 15, 1973, MSS band 7) flood hazard data for the southern scene. The original correlation was made at 1:100,000.

1. Perceptual image quality of bulk multispectral ERTS data is reported to be good only to scales of about 1:250,000.
2. Root mean square (rms) error in the location of well defined objects should be less than 75 meters in order to meet U.S. national map accuracy standards at scales of 1:250,000; the ground resolution of ERTS data has been reported to approach the 75 meter figure,
3. Internal and external distortions caused locational errors; rms distortion for the early multispectral scanner ERTS images was noted to be as great as 1000 meters, always greater than 300 meters. The distortional errors have been reduced to about 170 meters for precision multispectral scanner ERTS data, a figure which may be somewhat less for high contract linear objects.

For these reasons, the reliable use of the ERTS data at scales of 1:100,000 is not recommended and the 1:250,000 scale appears to be the greatest at which the data can be used for flood hazard mapping. This 1:250,000 scale is probably applicable only for the high contrast interfaces of the southern scene and the lower portion of the northern scene, not for the low contrast areas of the northern scene.

Tonal Anomalies in Pre-Flood Imagery

The dark tonal anomalies which correlate with flood-prone areas are visible in the southern scene as early as October 17

(figure 12). Pre-flood tonal anomalies are not noted on imagery taken prior to October 17. In the northern scene prior to January 15, no dark anomaly is observed except for the extreme southern portion immediately above Mobile Bay (also seen in the southern scene). Flood plains can be tentatively delineated prior to January 15, but the delineation is made on the basis of geomorphic features, not the dark tonal anomalies. The geomorphic features are not well displayed on any band and do not appear to be sufficient for flood mapping by themselves. They can, however, be used in conjunction with the dark tonal anomalies as described previously. Notation of the anomalies prior to flooding indicates that in the southern area some predictive capabilities can be obtained from the use of ERTS data and that pre-flood imagery might be used for flood mapping.

Delineation of Flood Hazard Areas and Correlation of U-2 and U.S.G.S. Data

U-2 imagery, flown over the region immediately north of Mobile Bay at a height of 18,000 meters on September 24, 1972, exhibits dark tonal anomalies analagous to those seen in the ERTS imagery. The original scale of the U-2 imagery is 1:130,000 and the correlation between these anomalies and known U.S.G.S. flood-prone areas in this region is extremely good (Figure 13). The scale of this correlation is 1:62,500, the scale of the U.S.G.S. maps. Areas of disagreement between U-2 and U.S.G.S. data are, in general, the same as those seen in Figure 6 , drawn with the ERTS data. However, there is more refinement and detail in the delineation of flood-prone areas and the regions of disagreement for the U-2 data are generally the same as those noted on the ERTS imagery, previously discussed.

FIGURE 12
ERTS image (multrispectral scanner band 7) taken on October 7, three months prior to flooding. Note the dark tonal anomalies for the drainage system north of Mobile Bay.

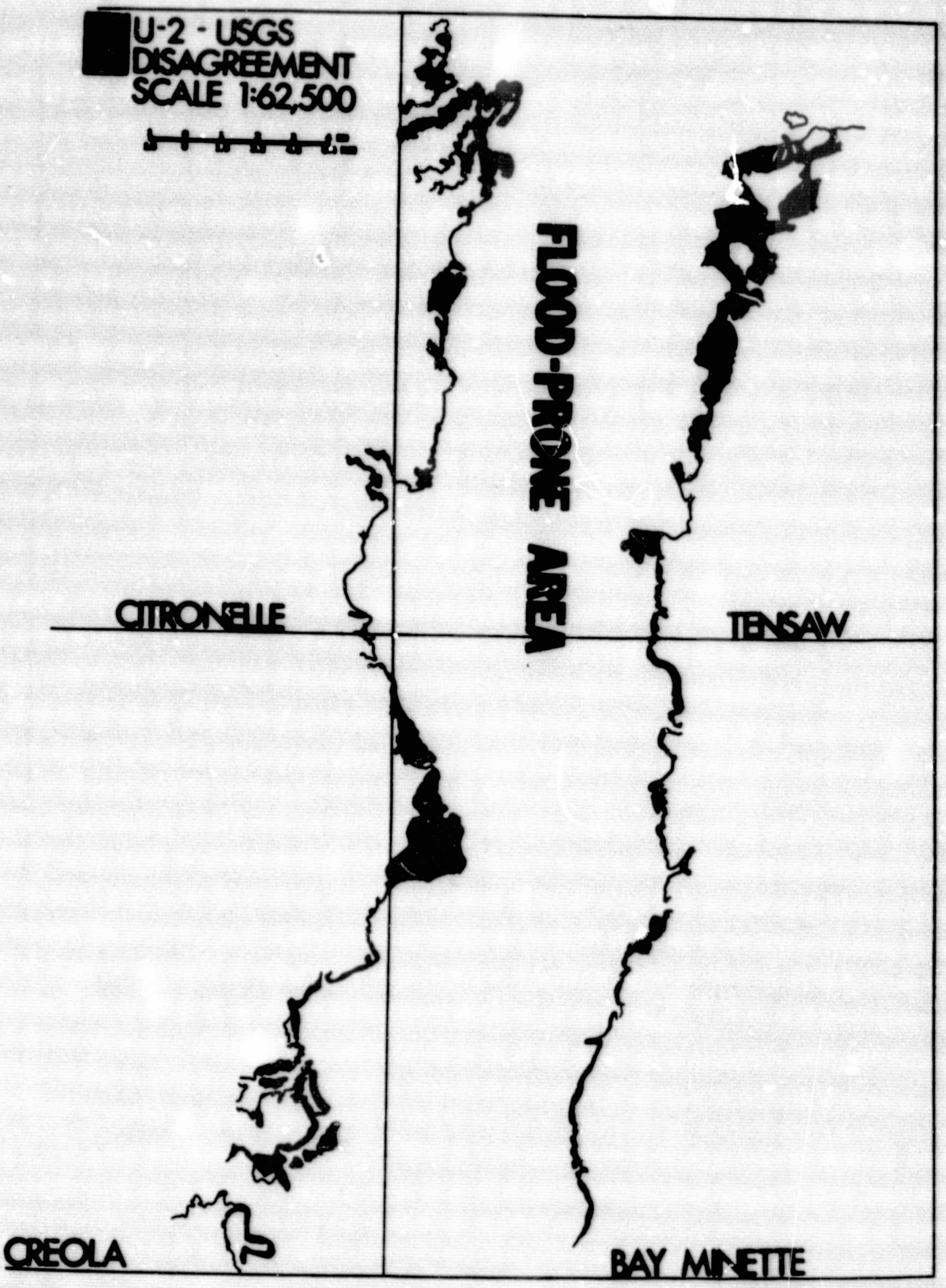

FIGURE 13
Correlation between USGS flood hazard data and U-2 flood hazard data for a portion of the southern scene. The original correlation was done at 1:62,500.

Note especially the areas in the northwest part of the Tensaw Quadrangle and in the southeastern part of the Creola Quadrangle. The correlation between the U-2 and U.S.G.S. data is for over 97% of the flood prone area and the discrepancies appear to be dominantly attributed to the 30 vs. 100 year flood-frequency for the two sets of data.

It is anticipated that the U-2 imagery could be enlarged for use at a scale of 1:24,000, that of the standard 7½ minute quadrangle. This was not done since the ground truth data (U.S.G.S. maps) were at a scale of 1:62,500 (15 minute quadrangles).

Cause of the Tonal Anomalies

To this point no mention has been made of the cause of the tonal anomalies which correlate with known flood-prone areas and appear to be useful in the mapping of flooded regions. Low reflectance in the infrared can be generally associated with water and the possible causes of flood plain low reflectance has been discussed by Hallberg and Hoyer, 1973; Parker and Wolff, 1973; and Rango and Anderson, 1973. Three principal causes for the low reflectance are:

1. the presence of standing or flowing water,
2. high soil moisture,
3. vegetation which is stressed due to extreme hydrologic conditions, thus reflecting less infrared radiation than unaffected plants.

Any one or combination of these variables may result in low infrared reflectance for the flood plains. It appears that the anomalies in the southwest Alabama area are due to a combination of these

variables. Low reflectance anomalies were noted as early as October 17, 1972, prior to innundation, and at that time were probably due to relatively high soil moisture. Unfortunately no ground truth soil moisture data are available for this time. The effect of stressed vegetation is also not known. During innundation of the land the low reflectance can be attributed, of course, to the higher water table. After innundation the cause is probably due to high soil moisture and possibly vegetation which was stressed due to flooding. Conceivably, through proper enhancement techniques, low reflectances attributable to different causes could be differentiated.

Economic Aspects of Flood Hazard Mapping

The costs of flood hazard mapping are highly variable. According to Wolman (1971) costs estimates may range from $1 to $4 per mile ($0.60 to $2.40 per km.) to $400 to $1,000 per mile ($6000) ($240 to $600 per km [$3600]) of channel. The exact upper cost limit of mapping is not entirely clear from Wolman's article. In it, he twice refers to $1,000 as the upper limit (pages 1383, 1384) and once states that $6,000 is the upper limit (page 1389). From personal discussions with U.S.G.S. personnel in Tuscaloosa, it appears that the $1,000 limit may be the more realistic. Wolman's cost estimates for flood hazard mapping by different techniques are noted in Table 1. Most of the lesser expensive techniques assume the existence of a topographic (or soils) base map and this cost is not incorporated into the flood hazard mapping cost figures. In contrast, the high cost for flood profiling and the drawing of backwater curves includes topographic

TABLE 1

Costs For Flood Hazard Mapping
(from Wolman, 1971)

METHOD	COST
Physiographic*	$1-4 per mile of channel
Soils*	$1-4 per mile of channel
Vegetation	Unknown
Occasional Flood	$200 per quadrangle or $4 per mile of channel
Regional Flood	$4 per mile
Flood Profiling and Backwater Curves*	$400-6000 per mile of channel

* assumes existence of topographic or soils maps

mapping. An intangible consideration is that the topographic map generated by this latter flood mapping technique can be used for other purposes and, therefore, side benefits are realized, which could effectively reduce the true cost of the flood mapping program.

The costs for flood hazard mapping from ERTS data (1:250,000 scale) are considerably less than those of standard techniques. Assuming that the technique is developed and that the ERTS images are photographed on standard 35 mm. film and projected to a 1:250,000 scale, total man hours spent for the mapping of the flood hazard areas in the two scenes discussed above would be between one and two hours. Total costs, including the purchase of the ERTS images, would range from \$10 to \$15. In the two scenes discussed above, over 400 kilometers of river channel were mapped (or checked against existing maps), not including the poorly interpretable area south of the Tombigbee--Black Warrior Rivers' junction; the costs per kilometer, therefore, would be from 2.5 cents to 3.8 cents if the process were repeated for a similar area. Also, no prior existence of topographic (or soils) maps is assumed; indeed no topographic maps exist for much of the Tombigbee River area. Costs for mapping from U-2 imagery, once the image is available, would be comparable. Such low costs make flood hazard mapping of rural or undeveloped areas highly feasible for large scale land use development.

Conclusions

In conclusion, it is found that ERTS and U-2 imagery can be used for the delineation of flooded and flood hazard areas. The multispectral scanner band 7, of the ERTS imagery appears to be

the best, but band 6 could possibly be used to almost as great a benefit. The flooded areas appear as dark tonal anomalies in the infrared. More specifically, the ERTS imagery can be used to verify existing flood hazard maps and can be used, either alone or in conjunction with geomorphological features, to map the extent of unmapped flood hazard areas. However, the presence of distinct dark tonal anomalies is needed for the most accurate mapping; if the anomalies are of low contrast or nonexistent, flood hazard mapping by use of ERTS data alone is difficult or unfeasible. The geomorphic flood plain features aid in the interpretation but must be used with caution since they may now represent non-flood-prone areas.

Although the ERTS data can be expanded for use at scales of 1:100,000, their accurate use at this scale is questioned due to distortional error within the ERTS data. These errors do not allow the interpretations of the data to meet national map accuracy standards for scales of 1:100,000. The scale of 1:250,000 is the maximum scale recommended for mapping of flood hazard areas from ERTS data.

U-2 imagery can be used similarly to the ERTS imagery. This can be done at a scale of at least 1:62,500 and, very possibly, at a scale of 1:24,000.

The economic considerations indicate that remotely-sensed infrared data offer a highly attractive method for flood hazard mapping at large scales. These costs for ERTS and U-2 flood hazard mapping are some orders of magnitude less than the traditional methods of flood-prone area mapping and do not require the prior existence of topographical or soils maps. Therefore, the

use of ERTS and U-2 data for flood hazard mapping could be readily applied to underdeveloped areas in large scale land-use evaluations.

One method of flood hazard mapping is by use of aerial photography during flooding; the standard recurrence interval for flood mapping is for the 100-year flood, which is a rare event. The high correlation between the U.S.G.S. 100-year recurrence interval data and the actual 30-year flood in southwest Alabama observed on the ERTS imagery, indicates that floods with a recurrence interval of considerably less than 100-years could be used to fairly accurately delineate 100-year flood limits in this area. This is beneficial since the more frequent floods could be more commonly studied and the data could be projected to the 100-year level. This observation appears to hold for most of the area studied. It should be more fully verified and should not arbitrarily applied to topographically dissimilar areas.

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